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A MOBILITY ANALYSIS OF VEHICLES PARTICIPATING IN S-TANK AGILITY-SURVIVABILITY (STAGS) TESTING

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U. S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
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A mobility analysis is conducted of seven vehicles participating in the S-Tank Agility-Survivability (STAGS) testing. Acceleration and cross-country performance are modeled in a variety of terrain conditions. In addition, performance on a test course is modeled and the results compared with those obtained during testing. Finally, the vehicles are ranked according to their overall mobility in both European and Mid East terrain.

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A MOBILITY ANALYSIS OF VEHICLES PARTICIPATING IN S-TANK AGILITY-SURVIVABILITY (STAGS) TESTING

1. BACKGROUND

A Force Development Test and Experimentation (FDTE) effort was conducted by the TRADOC Systems Analysis Activity as part of the S-Tank Agility/Survivability (STAGS) evaluation program (reference 1). In conjunction with the FDTE, the Waterways Experiment Station (WES) conducted several vehicle performance tests informally reported in reference 2. Subsequent to completion of the test programs, a mobility analysis of the four tested vehicles and three partially tested vehicles was conducted by TRASANA. AMSAA was requested to support this analysis through consultation by interpreting the modeling results obtained. Discovery of certain anomalies in the original data resulted in a decision to repeat and extend the analysis to applying the mobility models as they exist in AMSAA. This report contains the results of the AMSAA evaluation.

2. OBJECTIVES

The analyses described herein were structured to satisfy the following objectives:

a) to provide a comparison of the mobility (as reflected by cross country speed) of the seven vehicle systems considered in STAGS.

b) to provide a comparison of agility potential for these seven vehicles using straight-ahead acceleration as a measure.

c) to model performance of the STAGS vehicles on the FDTE course at Fort Knox and compare these results with those obtained through testing.

d) to examine the impact of vehicle characteristics through diagnosis of those factors limiting speed in a variety of cross country terrain.

3. ANALYSIS

The seven vehicles considered are:

- S-Tank - Swedish turretless medium tank
- M60A1 - US MBT
- M113A1 - US APC
- RVT - FRG test bed on an M41 chassis

- o XM808 - Twister, 8-wheel drive, roll articulated test rig
- o FMC - XM800-T vehicle sans turret
- o M113-2 - Waterways Experiment Station test vehicle; M113 hull with two engines.

In Appendix A, there are detailed descriptions of these vehicles; these are sufficient to permit the required mobility modeling.

3.1 Methodology.

Two vehicle-terrain simulation models were utilized in this analysis. The AMC '71 Mobility Model was used to predict vehicle mobility (as a function of cross-country speed). The AMSAA Acceleration Model predicts straight line vehicle acceleration and thus provides a measure of vehicle agility. Each of these models is discussed briefly below.

3.1.1 AMC '71 Mobility Model. This model considers vehicle performance in both areal and linear type terrain features. (Areal features are those distributed in two dimensions over a surface; linear features are those occurring along a line, such as a river or ravine.) The areal mobility prediction part of the AMC '71 Mobility Model (which is the only portion used in this evaluation) is shown schematically in Figure 1.* The fundamental operation of this model follows. Detailed areal terrain data are collected from existing terrain data sources, such as topographical maps, air photos, terrain studies, agricultural data and soil maps. Where possible, these data sources are supplemented by actual field surveys. All these data sources are then used to develop a series of individual maps of the area being considered for each of the terrain factors shown in Figure 1.

The terrain input processor accepts these maps and overlays them to define areas in which the terrain is homogeneous with respect to all of the terrain factors simultaneously. The result of this process is an areal terrain unit map as shown in Figure 1, where unit number 98 might reflect an area where the slopes are uniformly between 5 and 10 percent and the soil strength in the wet season is uniformly between 40 and 60 cone index, etc. Associated with each map unit number is a range of values for each of the 13 terrain factors. For example, areal terrain unit number 14 may have the following detail factor value listing: 1 5 3 9 4 3 5 1 1 3 1 5 4 3 3 2 1 1 3

*Figures and tables are located at the end of the report.

Where the detail factor values are as follows:

	Factor Value	
1.	1	Soil type - fine grain
2.	5	Soil strength (wet) -61 to 100 remolded cone index (RCI)
3.	3	Slope - 5.1% to 10%
4.	9	Obstacle approach angle 149.1^{o} to 158^{o}
5.	4	Obstacle vertical height 36 to 45 cm
6.	3	Obstacle base width 61 to 90 cm
7.	5	Obstacle length 3.1 to 6.0m
8.	1	Obstacle spacing Bare > 60M
9.	1	Obstacle spacing type random
10.	3	Surface roughness 2.6 to 3.5 RMS* in.
11/12.		Spacing of vegetation stems equal to or greater than
	1	0 cm dia. bare
	5	2.5 cm dia. 5-6 - 8m
	4	6.0 cm dia. 8-1 - 11m
	3	10.0 cm dia. 11-1 - 20m
	3	14.0 cm dia. 11-1 - 20m
	2	18.0 cm dia. 20m
	1	22.0 cm dia. bare
	1	25.0 cm dia. bare
13.	3	Visibility range 12-1 - 24m

* Root mean square

Areal terrain unit maps were developed by the US Army Engineer Waterways Experiment Station (WES) for the operational area utilized in the analysis. The areas involved reflect 159 square miles in Germany near Fulda, 212 square miles in Jordan, and a course length of 20.2 miles at Ft. Knox, KY. Distribution of some of the important terrain factors in these areas are given in Table 2.

The model requires a total of seventy-six vehicle characteristic inputs. These range from vehicle size and weight to details of its power train and suspension components. With these data the various mathematical submodels of the overall model predict vehicle performance in the terrain factor values established for each map unit.

Submodels consider vehicle performance through the following:

Terrain Factors Considered	Vehicle Performance Predicted
Soil type Soil strength Slope	Tractive and resistive Forces throughout speed range.
Terrain roughness	Ride limited speed
Obstacles	Hangup, traction, dynamic loading, acceleration, and braking between obstacles.
Vegetation	Traction for overriding, and vehicle size for maneuvering between trees. Driver visibility.

For a given map unit, the speed result of each of these submodels is examined for both uphill, downhill, and level conditions, and the limiting value is selected as the vehicle's best speed in that map unit. In considering the vegetation factor the model examines various strategies of maneuvering around certain size trees and overriding others to obtain the best vehicle speed. Some terrain factors, such as soil strength and slope naturally interact with others and are considered simultaneously. For example, a vehicle on a soft soil slope will have less tractive force available to climb an obstacle or override a tree than it would on a level hard surface because some of its tractive force capability is used in overcoming the soft soil motion resistance and the grade resistance. The basic speed output of the model can be used to develop a speed map as shown in Figure 1.

3.1.2 The AMSAA Acceleration Model. This model is based on an earlier acceleration routine developed at TACOM. It computes acceleration for both wheeled and tracked vehicles on fine grain and coarse grain soil, and on paved or secondary roads, and includes the resistance due to surface grade. The model contains empirical expressions for the power lost in accelerating the rotating parts within the vehicle as well as for the air resistance encountered. The model output is velocity and distance as a function of time.

3.2 Acceleration Performance.

The AMSAA Acceleration Model was run for each of the seven vehicles considered in STAGS. Each vehicle was run on 120 RCI and 60 RCI fine grain soil with slopes of Ø percent and 20 percent for each soil strength.

Figures 2 through 5 are plots of vehicle speed versus time with all seven vehicles appearing on a single plot for a given soil-slope condition. These plots along with Table 1 can be used to rank the vehicle's relative agility potential. It should be noted that agility potential is being considered here only as a function of straight line acceleration capability and that there are other vehicle parameters which affect agility. These could alter an agility ranking based solely on forward acceleration capability.

In order to provide better indication of the significance of differences in acceleration capability existing among the vehicles, Table 1 also shows the time to cross certain gap distances under the specified soil and slope conditions. The gap distances shown were found in reference 5 to be the mean distance between cover positions at three different locations in West Germany.

The M113-2 is shown to accelerate faster than all the other vehicles on all soil-slope conditions. On Ø percent slopes in 120 and 60 RCI soils its predicted top speed is only slightly lower than that of the XM808, and on 20 percent slopes its predicted top speed is higher than the top speed of the XM808. On a level 120 or 60 RCI surface the RVT accelerates faster than the XM808 until it reaches approximately 40 mph where its speed levels off and the XM808 continues to accelerate up to 64 mph. On 60 RCI soil and 20 percent slope, however, the RVT accelerates faster than the XM808 and also has a higher top speed, while on 120 RCI and 20 percent slope, it still accelerates faster and has only a slightly lower top speed. Thus, on overall off road agility the M113-2 ranks first, the RVT second, and the XM808, third. The rest of the vehicles are relatively easy to order since the acceleration curves in all cases are nearly parallel. The XM800T would rank fourth, and it is considerably faster than the last three vehicles which are the M113-A1, M60-A1, and the S-tank, in that order.

3.3 Cross Country Performance.

The seven STAGS vehicles were run on the AMC '71 Mobility Model in Mid East and West German terrain. A partial description of these areas is given in Table 2. Model output is most readily interpreted in graphical form. There are two sets of graphs for each terrain considered. To generate these plots the terrain units are first ordered according to vehicle speed attained in the unit in decreasing order from highest to lowest speed. Cumulative average vehicle speed and actual vehicle speed are then plotted against percent of total area. Cumulative average speed is defined as the average of the speeds in all terrain units included up to the selected point on the total area axis. The actual speed curve shows in actual speed potential in the immediate terrain unit, not average with all previous units. These plots appear in Figures 6 through 11. Tables 3 through 11 give the V-50 (cumulative average vehicle speed over the most trafficable 50 percent of the terrain), V-90 (cumulative average vehicle speed over the most trafficable 90 percent of the terrain), and the percentage of terrain which the vehicle could not negotiate (percent no-go). An analysis of predicted vehicle performance on West German terrain shows that the XM808 maintains the highest speed of the seven vehicles. The next fastest over this terrain are the RVT and XM800T. The RVT is 5.6 mph slower at V-50 than the XM808, while the XM800T is 7.6 mph slower. At V-90 both vehicles have nearly the same cumulative speed, 5.8 mph slower than the XM808. The RVT has approximately the same percentage of no-go's as the XM808, however, the XM800-T has a very low percentage of no-go's; its percentage of area denied being only 1.8 percent as compared with 5.2 percent for the RVT and 5.6 percent for the XM808. The M113-A1 and the M113-2 had the same percentages of no-go's at 4.7, the M113-2 averaged a much higher predicted speed over the terrain, although not as high as the RVT. The M60-A1 and the S-Tank are very close in predicted performance over the West German terrain; however, the S-Tank has a higher percentage of no-go's with 4.6 percent as compared to 2.6 percent for the M60-A1.

An analysis of vehicle performance on the Mid East terrain reveals a much narrower speed range for the seven vehicles (18.6 mph spread in West Germany for V-50 vs 6.0 mph spread in Jordan; and a 12.8 mph spread in West Germany for V-90 vs a 5.6 mph spread in Jordan). This, of course, is due to the fact that the greatest difference in the vehicles is in the power train performance. In terrain such as Jordan's the high degree of roughness is such that suspension performance controls the speed and large advantages in available power simply cannot be utilized. There was also a much wider range in percent no-go for the seven vehicles (3.4 percent spread in West Germany and a 20.8 percent spread in Jordan). In ranking the vehicle's relative mobility in this terrain, consideration must be given to percent of vehicle no-go's as well as, to cross-country speed. In the most easily trafficable terrain segments the XM808 is the fastest of the seven vehicles. As the terrain becomes more difficult the cross-country speed of the XM808 drops rapidly. After approximately 70 percent of the area has been traversed, only the RVT and the S-Tank have lower cumulative average speeds. Percent of no-go's is also very high for the RVT, S-Tank, and

XM808. The XM800T has the best performing vehicle on this terrain. The M60-A1 had a slightly lower V-50 than the M113-2 and a much higher V-90. The M113-A1 was only slightly slower than the M113-2.

As can be seen from Table 2, the Mid East terrain has more severe surface roughness and obstacle magnitude factors than does the West German terrain. The West German terrain has more severe soil strength and slope factors, however. A comparison of the distribution of speed limiting factors for the seven vehicles (Tables 12 and 13) on the West German and Mid East terrain reflects this difference in terrain characteristics. All vehicles have much higher percentages of no-go's due to obstacles on the Mid East terrain; the percentage of total area in which the vehicles were limited by ride dynamics is also much higher on the Mid East terrain. For most of the vehicles, speed is frequently limited by surface/slope conditions on the West German terrain. On such terrain, a high power/weight ratio gives the vehicle an advantage, while on Mid East terrain the ability to negotiate difficult obstacles and good ride dynamics are more important to good vehicle performance. This point is illustrated by comparing the performance of the M113-A1 with the M113-2 on the two terrains. On West German terrain the M113-2 has a 5 mph higher V-50 and a 2.9 mph higher V-90 than the M113-A1. The percentages of no-go's are the same for both vehicles. On Mid East terrain, however, the M113-2 is only 0.1 mph faster at V-50, and 1.5 mph faster at V-90 than is the M113-A1. The M113-2 with 3.2 times higher horsepower/ton is only marginally faster on the Mid East terrain. Very high power gave the M113-2 a significant advantage over the M113-A1 on the German terrain but virtually no advantage on the Mid East terrain where their nearly identical ride and obstacle characteristics resulted in nearly identical performance.

The seven STAGS vehicles were also run in the AMC '71 Mobility Model using terrain data representing the FDTE course at Ft. Knox, KY. This course was partitioned into seven "events" (reference 1) in the same way as the course at Ft. Knox. Further information on the Ft. Knox terrain data appears in Table 2.

Soil strength, slope, surface roughness, and obstacle factors are less severe on the Ft. Knox course than on either the West German or Mid East terrains. For this reason, the vehicles with very high horsepower/weight ratios have a performance advantage since there are no difficult obstacles to negotiate and the surfaces are relatively smooth (75 percent of course length has an RMS roughness < .8 each).

Figures 12 through 18 are plots of predicted vehicle speed as a function of percent segment length, where the high speed portions of the event are considered first. Figures 19 and 20 give predicted performance over the entire combined seven segments. The best performing vehicle over the entire course is the XM808. The M113-2 and XM800T are very close in overall performance and average approximately 5 mph slower than the XM808. The RVT is close in overall predicted speed performance to the M113-2 and XM800T. The predicted performance of the M113-A1 is approximately midway between the 4 fastest vehicles and the two slowest. The M60-A1 and the S-Tank have the slowest predicted speeds over the Ft. Knox course and the M60-A1 has a slight speed advantage over the S-Tank.

3.4 Comparison with STAGS Test Results.

In order that analytically generated mobility assessments made in prior sections might be validated to some degree, comparisons are made in this section of the modeled performance with that actually obtained during STAGS testing.

The FDTE course, as characterized by Waterways Experiment Station in 1974 for AMSAA, is somewhat different from that run in STAGS testing. The following chart identifies differences in course length and event structure.

FDTE Course Summaries

STAGS		1974 WES Characterization	
Event	Length (Mi)	Event	Length (Mi)
1	2.15	1	2.3
2	3.14	2	3.4
3	0.93	3	1.0
4a	3.13	4	3.4
4b	2.50		
5	2.60	5	2.7
6a	1.46	6	1.6
6b	2.49		
7	5.45	7	5.8
TOTAL	23.85		20.2

Table 15 provides a basis for comparing the mobility modeling output using the 1974 course characterization with results from the STAGS testing. The table indicates the order of ranking of the six vehicles for which test data are available, as determined both by testing and by modeling. Results are shown for each event in the FDTE course and for the overall course. As an indication of the differences in performance that exists between rankings, the average speeds in MPH are also shown.

Some important observations are that:

a. The modeling provides an accurate assessment of the relative mobility of the test vehicles.

b. The modeling consistently predicts speeds higher than the testing.

c. Under the FDTE course conditions, the XM808 offers the greatest mobility, followed closely by the XM800-T and the RVT. The M113A1 is the clearcut middle performer and the M60A1 and S-Tank are the poorest performers.

Some elaboration on item "b" is in order. It should be recognized that the modeling employed in this evaluation is structured to identify the maximum vehicle automotive performance attainable in the terrain specified. Military drivers generally do not have the training or experience necessary to extract this maximum performance from the vehicle in all types of terrain conditions. Highly skilled test drivers, on the other hand, have demonstrated ability to develop vehicle performance which closely matches that predicted by the modeling (Appendix B).

There is another factor that contributed significantly to lower test performance. Contained within the individual "events" on the course were a number of check points (varying from one to ten). At each check point the vehicle was brought to a halt while data were recorded, then accelerated again to the travel speed. The modeling, however, assumed continuous vehicle movement at maximum speed, and did not account for the frequent deceleration and acceleration at check points.

Based on the above arguments, it is hypothesized that modeling results offer a good assessment of each vehicle's mobility potential. Furthermore, it is believed that the extrapolation of the mobility assessment, through modeling, to the West German and Jordan terrains, is valid.

3.5 Summary.

The results of the preceding mobility analyses are summarized in Table 16; this also provides a mobility ranking of the vehicles in several terrain situations (agility will be considered separately). The three factors which entered into the rankings are shown in the table. They are the average speed in the most trafficable 50 percent of the terrain (V_{50}), the average speed in the most trafficable 90 percent of the terrain (V_{90}), and the percent of terrain that will not permit passage of the vehicle. The first of these measures, V_{50}, is intended to represent performance off road in non-combat situations such as rear areas or movement to combat, where greatest latitude in path selection is available. The second, V_{90}, is intended to represent movement in the combat situation, and is the most critical for vehicles of the type analyzed herein. The third measure, the area denied, is a measure of marginal terrain capability, and is likewise important to combat success.

The rankings reveal the following:

1. In a temperate environment such as is typically found in central Europe, a high performance power train is the principal contributor to mobility performance.

2. In an arrid environment, as is typically found in the Mid East, the surface is firmer and less hilly, but considerably rougher with large obstacles present. Power train performance is of marginal benefit here unless commensurate improvements are also made in hull design in order to reduce interference and in the suspension in order to improve ride quality.

Since no measures of turning capability or sustained lateral acceleration capability were available from either modeling or test data, only straight-ahead acceleration is used to rate the agility of the vehicles. This factor was evaluated in section IIIB and resulted in the following rankings:

1. M113-2
2. RVT
3. XM808
4. XM800T
5. M113A1
6. M60A1
7. S-Tank.

FIGURES

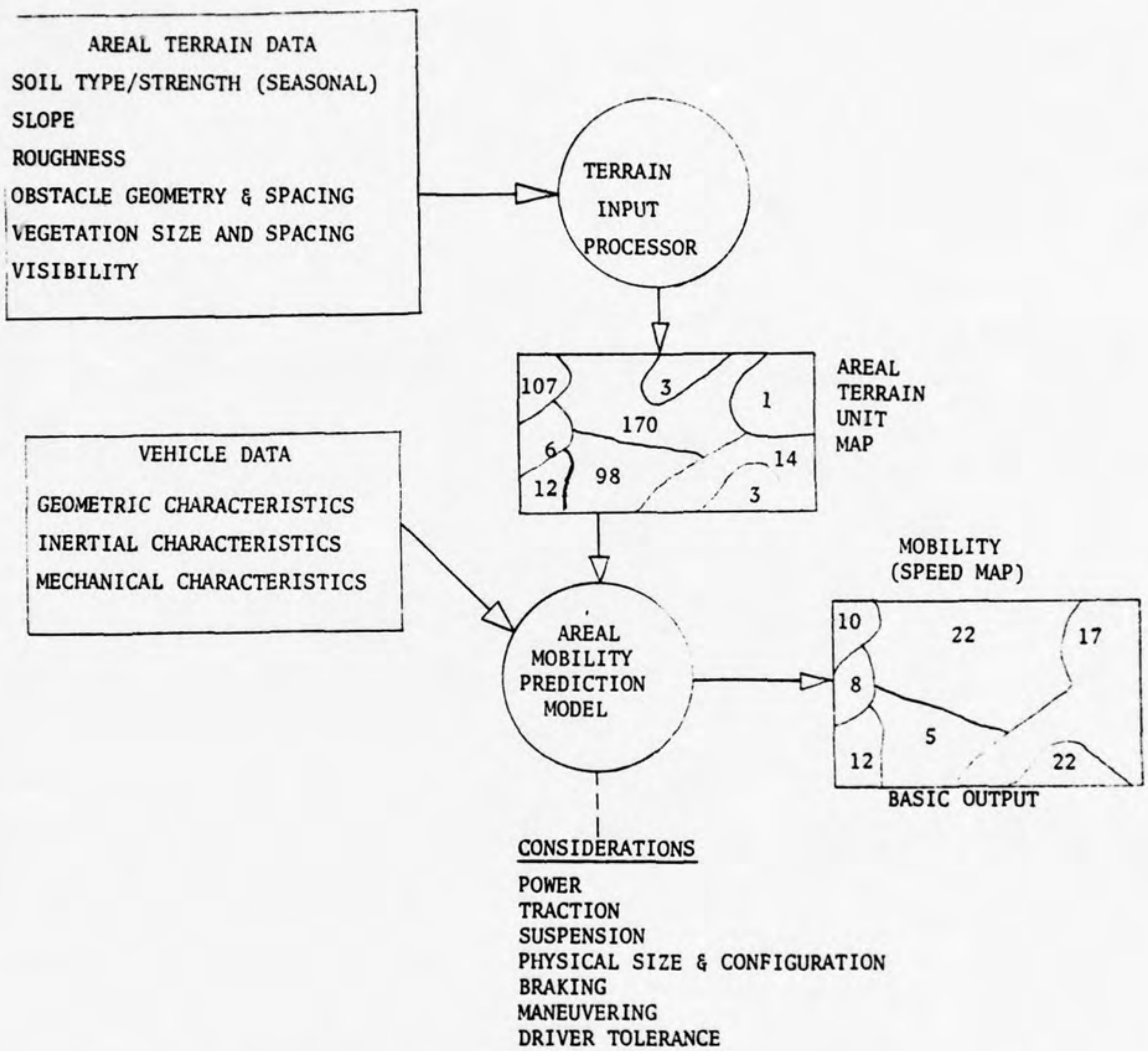


FIGURE 1 AMC MOBILITY MODEL (AREAL MOBILITY PREDICTION)

FIG. 2

ACCELERATION ON 12Ø RCI FINE GRAIN SOIL Ø% SLOPE

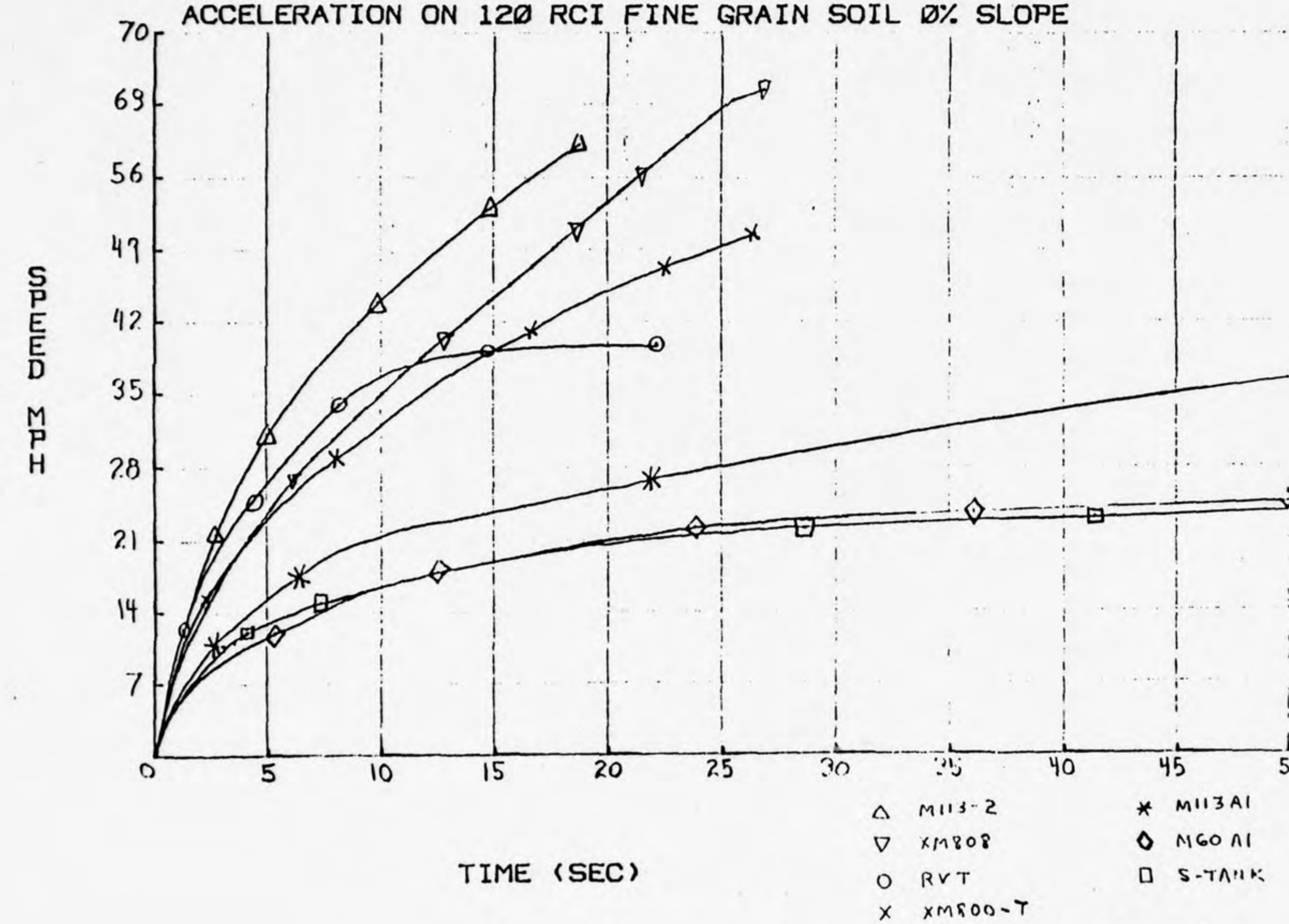


FIG. 3

ACCELERATION ON 12Ø RCI FINE GRAIN SOIL AND 2Ø% SLOPE

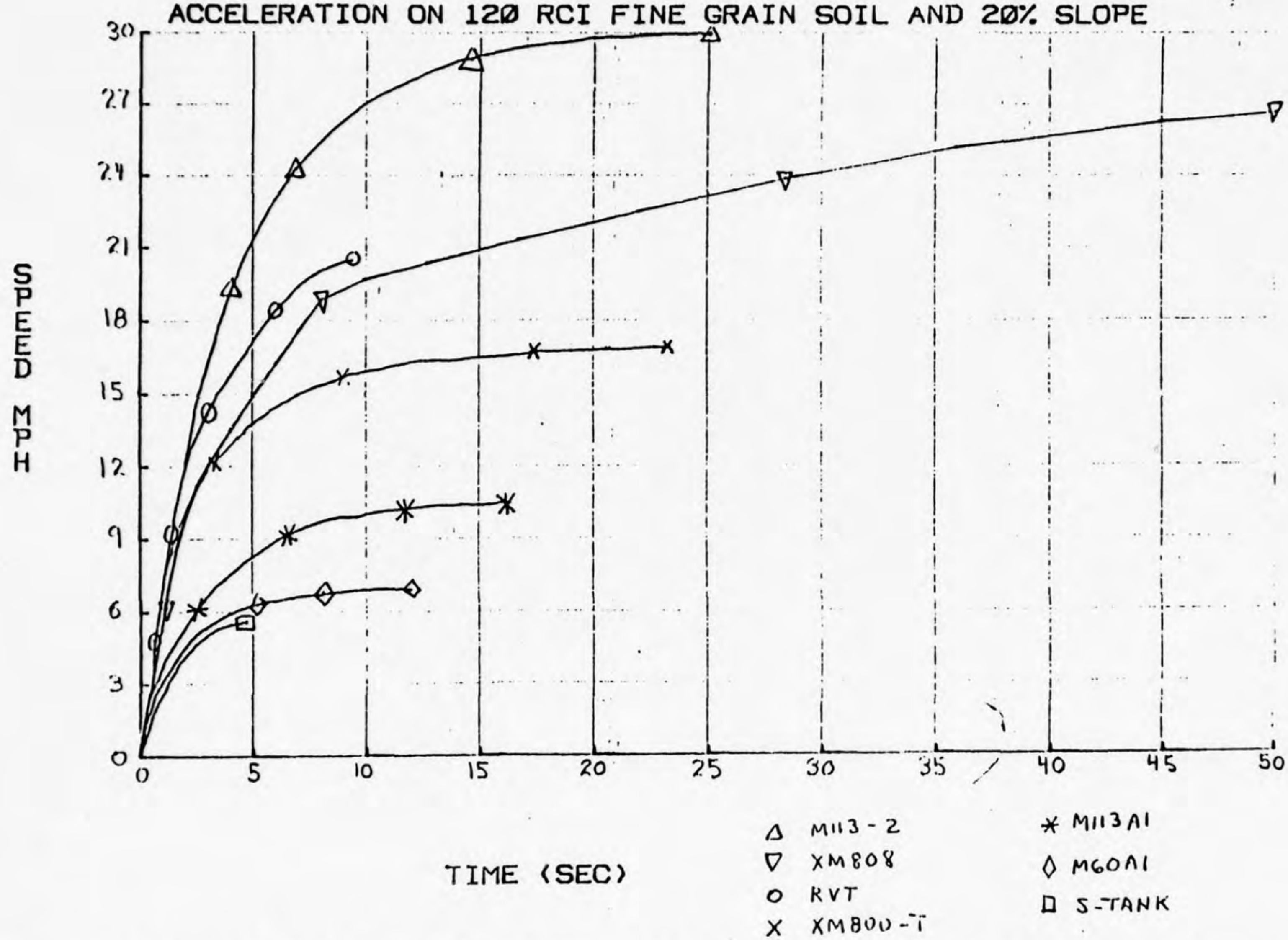


FIG. 4

ACCELERATION ON 60 RCI FINE GRAIN SOIL 0% SLOPE

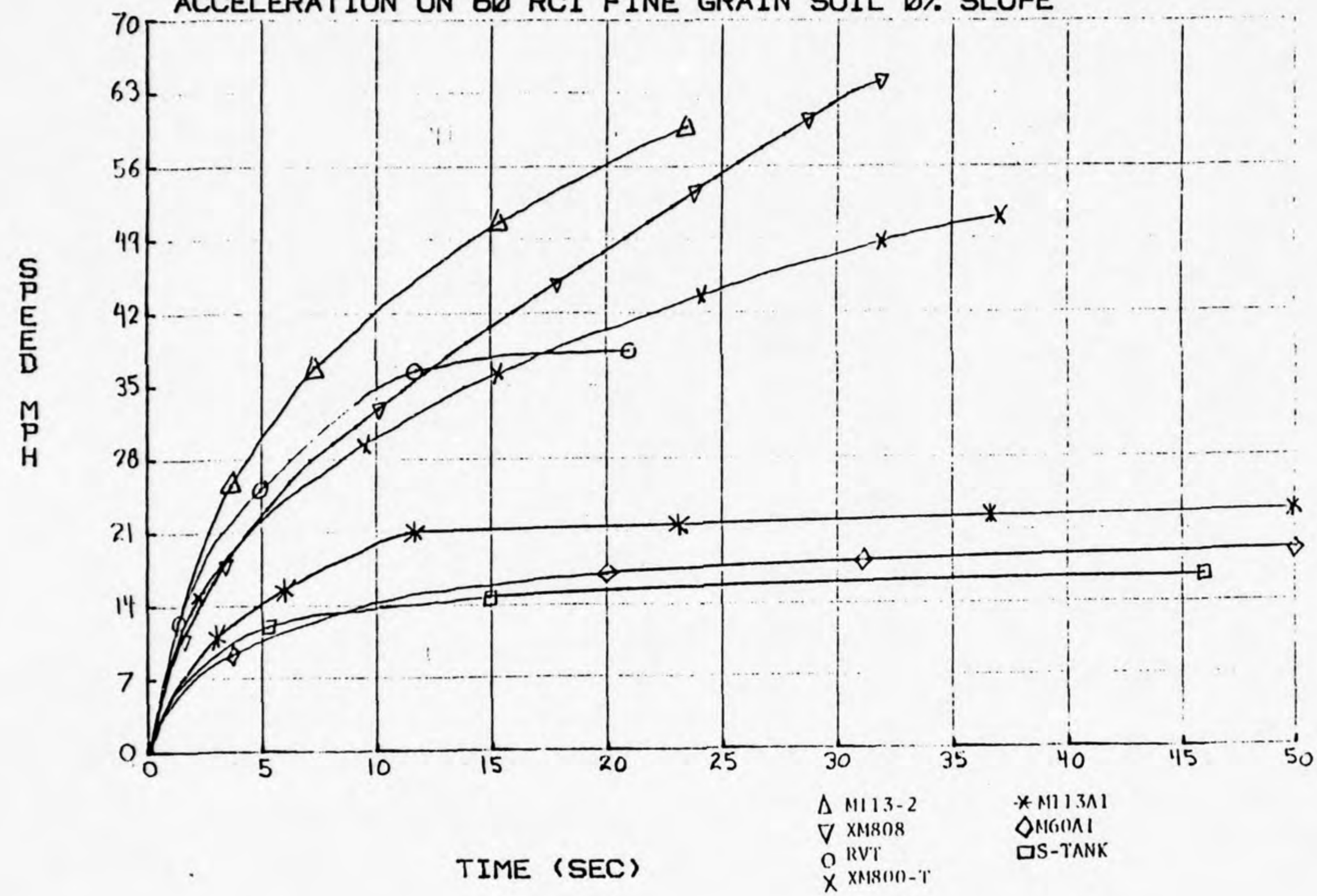


FIG. 5

ACCELERATION ON 6Ø RCI FINE GRAIN SOIL 2Ø% SLOPE

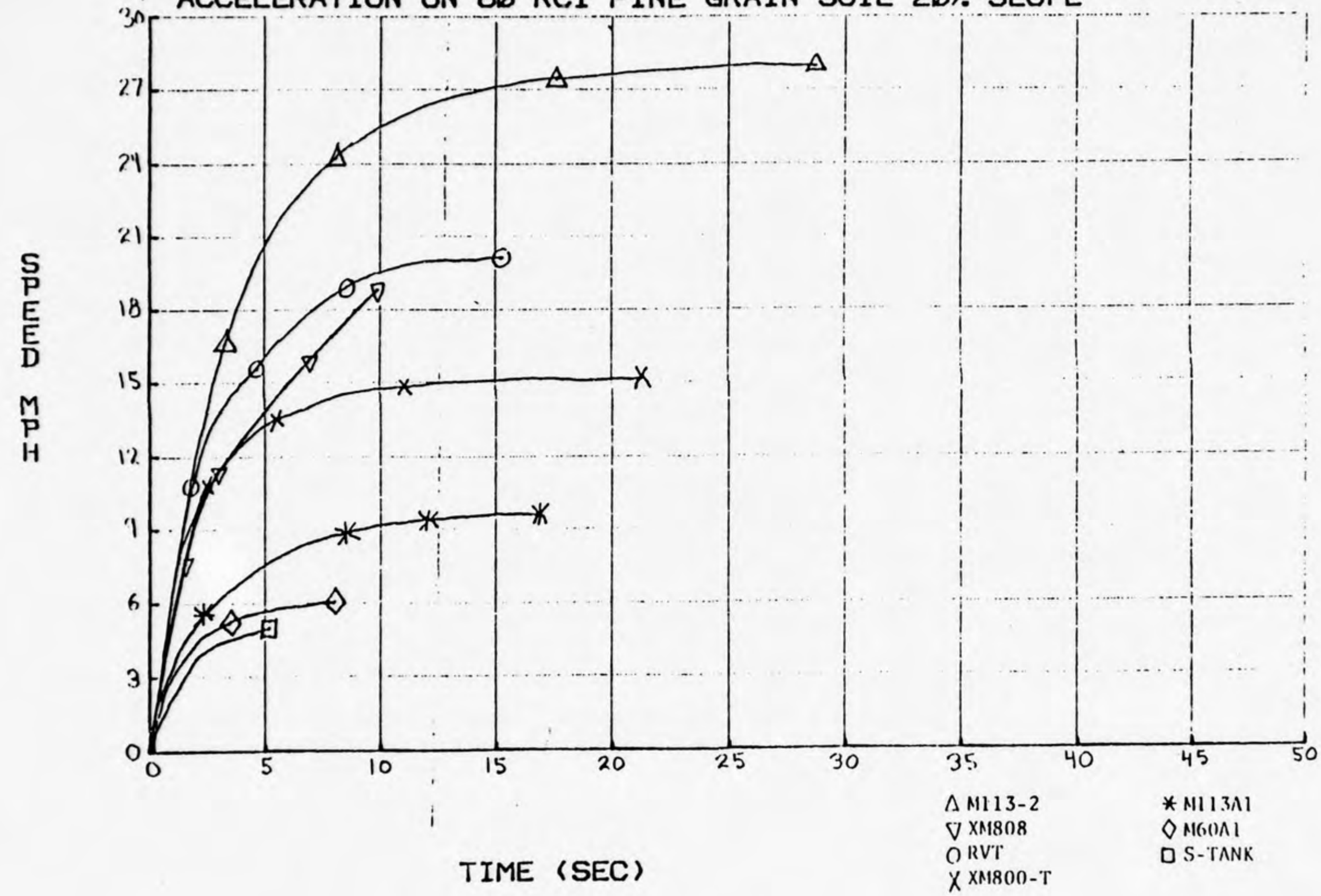


FIG. 6 : VEHICLE PERFORMANCE ON WEST GERMAN TERRAIN

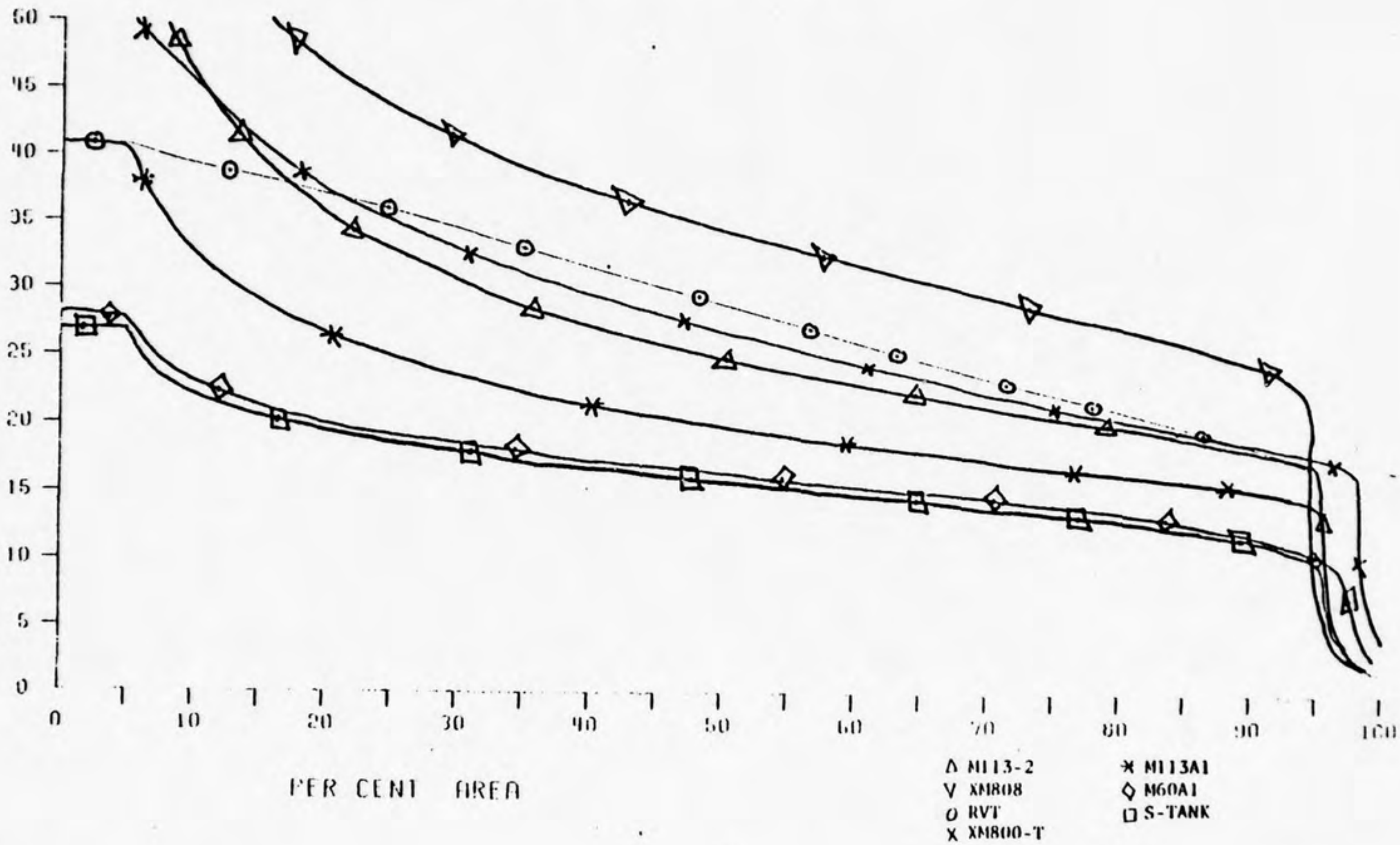


FIG. 7: VEHICLE PERFORMANCE ON WEST GERMAN TERRAIN

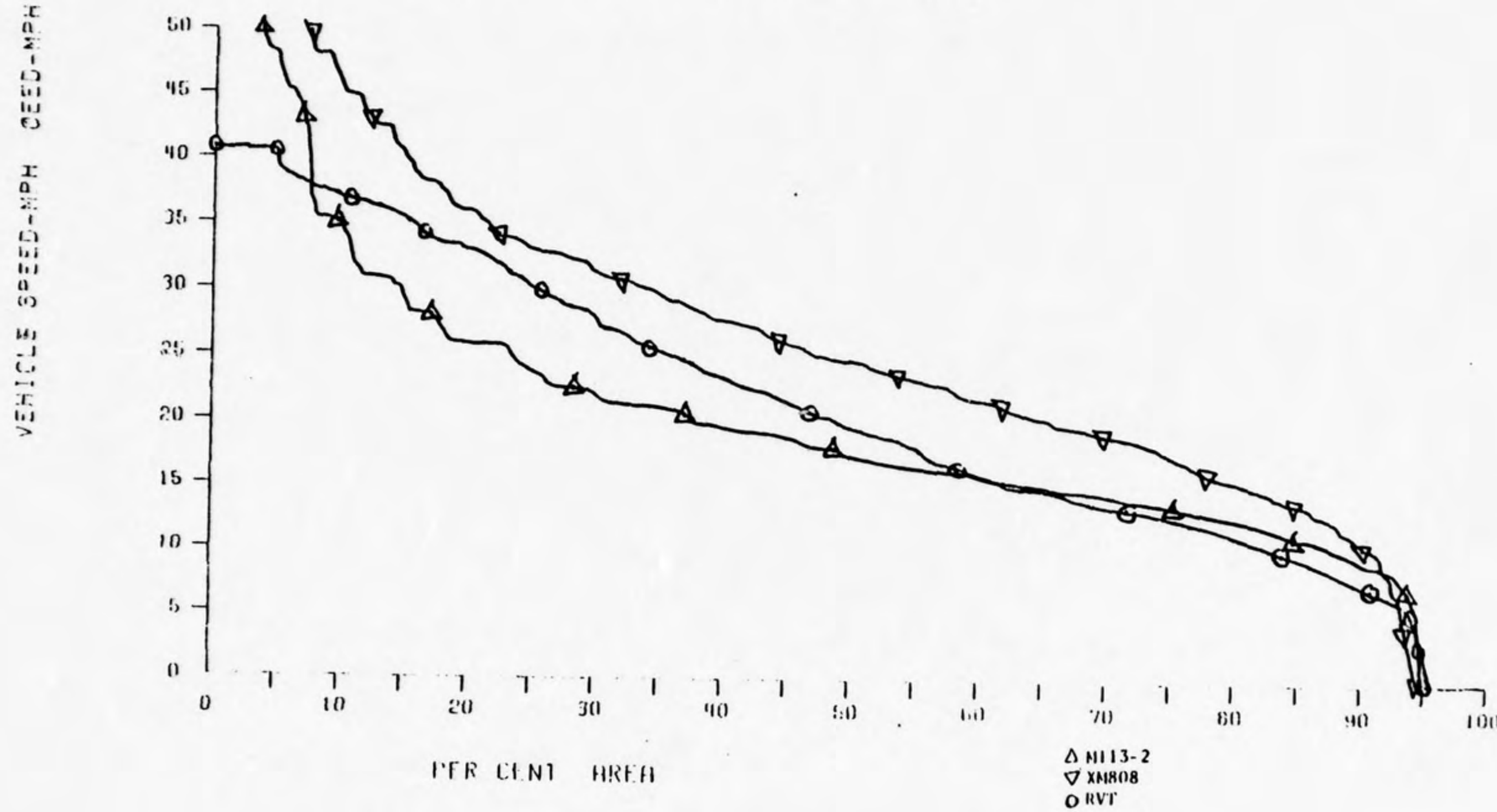
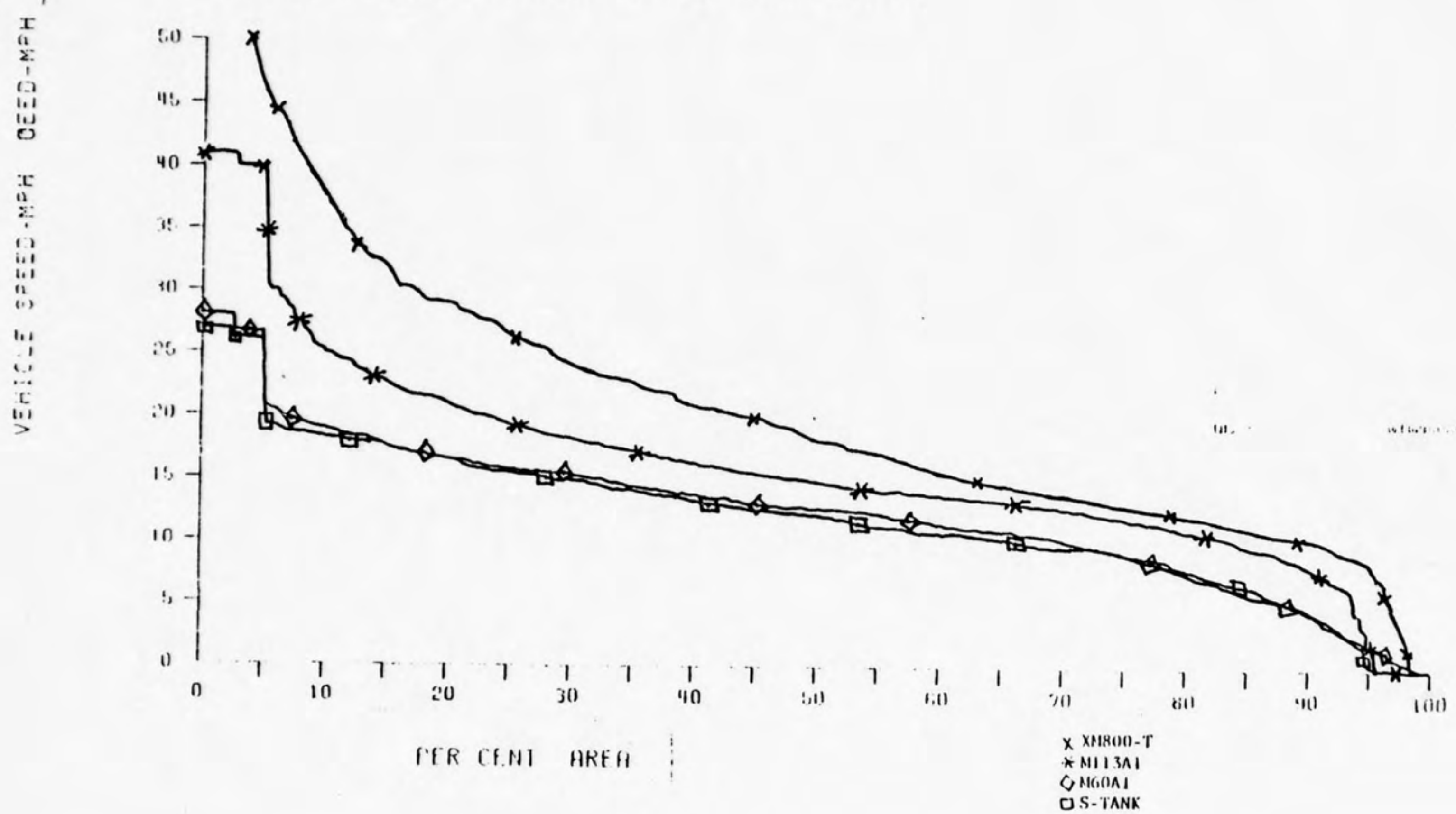


FIG. 8 : VEHICLE PERFORMANCE ON WEST GERMAN TERRAIN



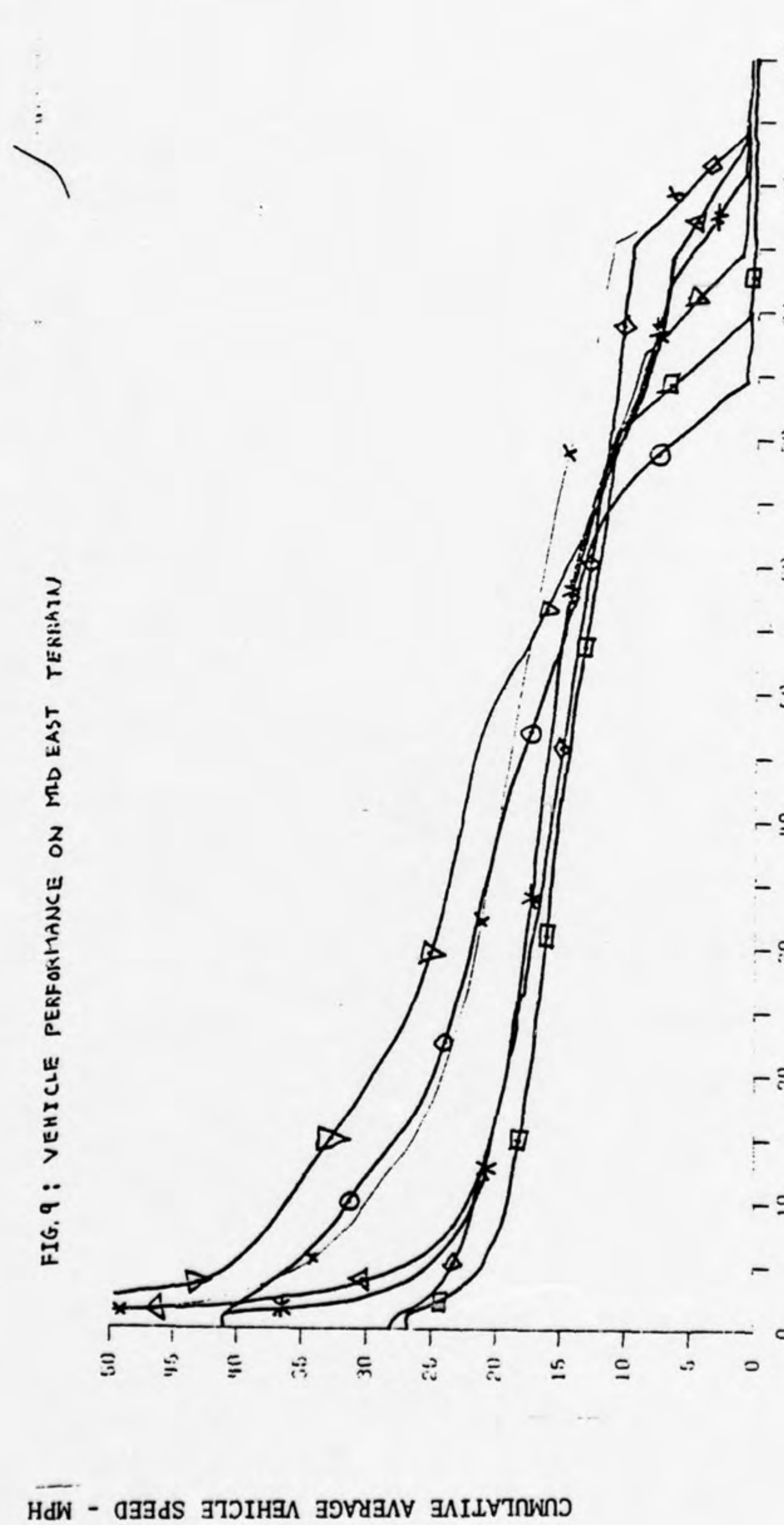


FIG. 9: VEHICLE PERFORMANCE ON MID EAST TERRAIN

FIG. 10: VEHICLE PERFORMANCE ON MID EAST TERRAIN

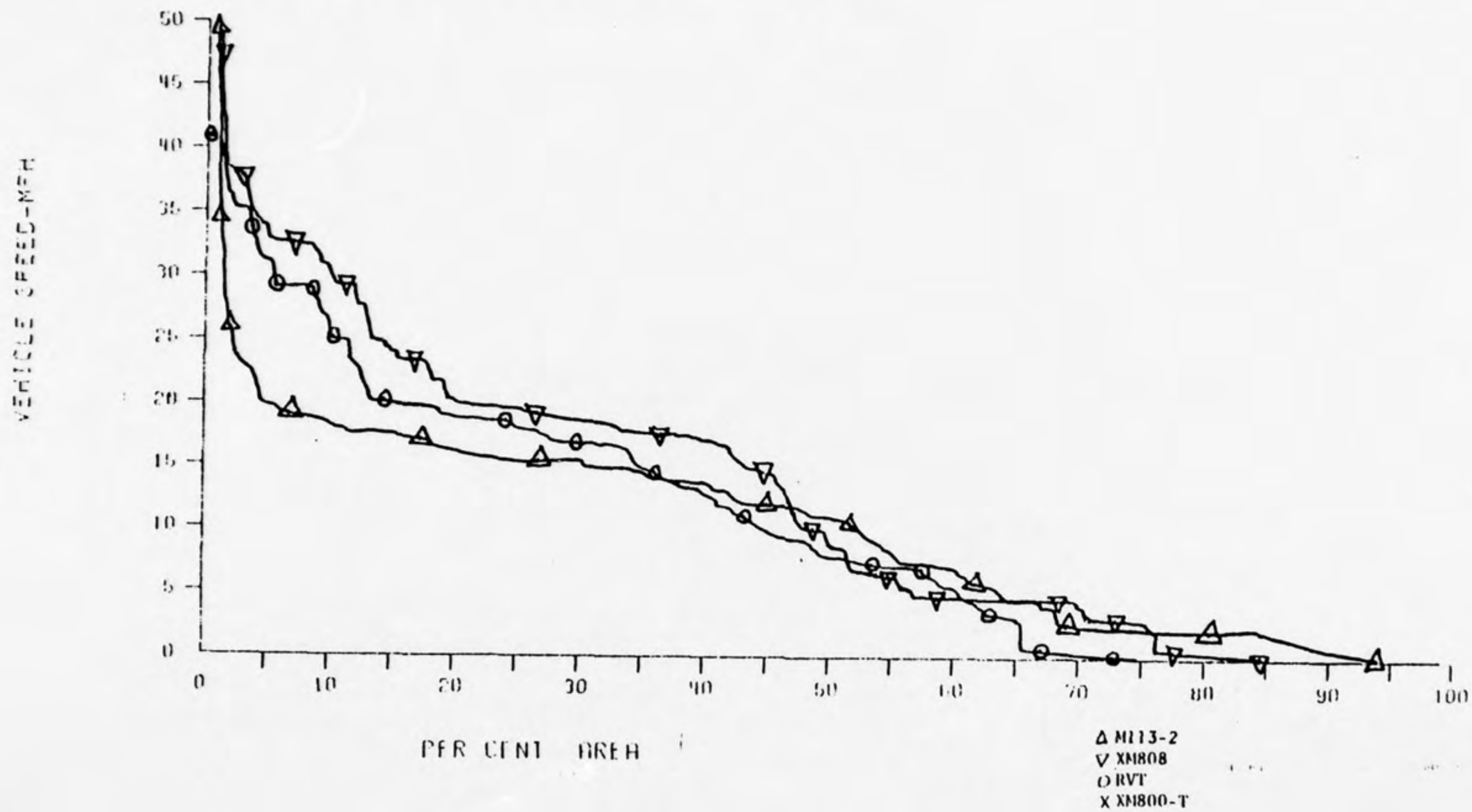
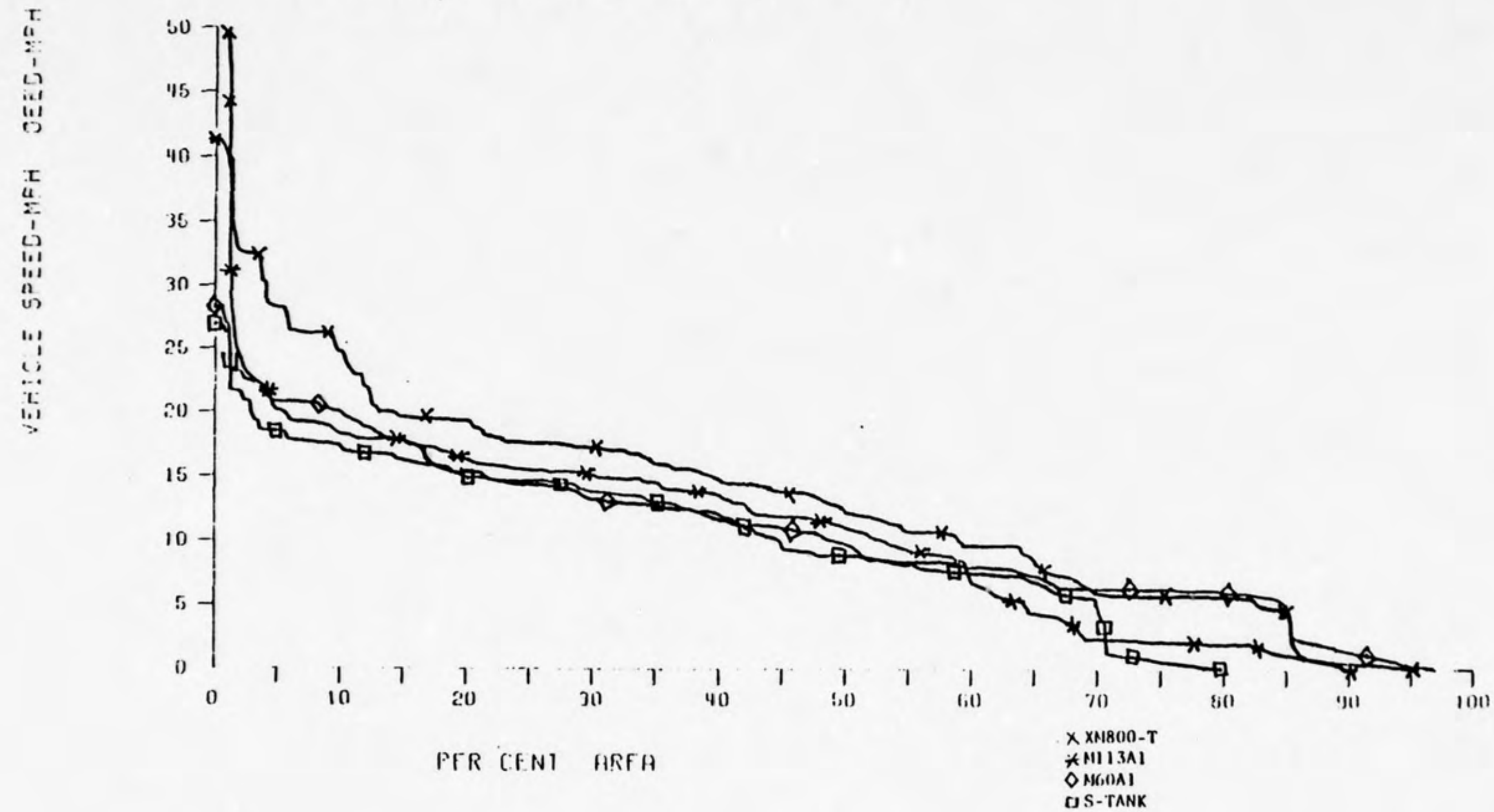


FIG. II : VEHICLE PERFORMANCE ON MID EAST TERRAIN



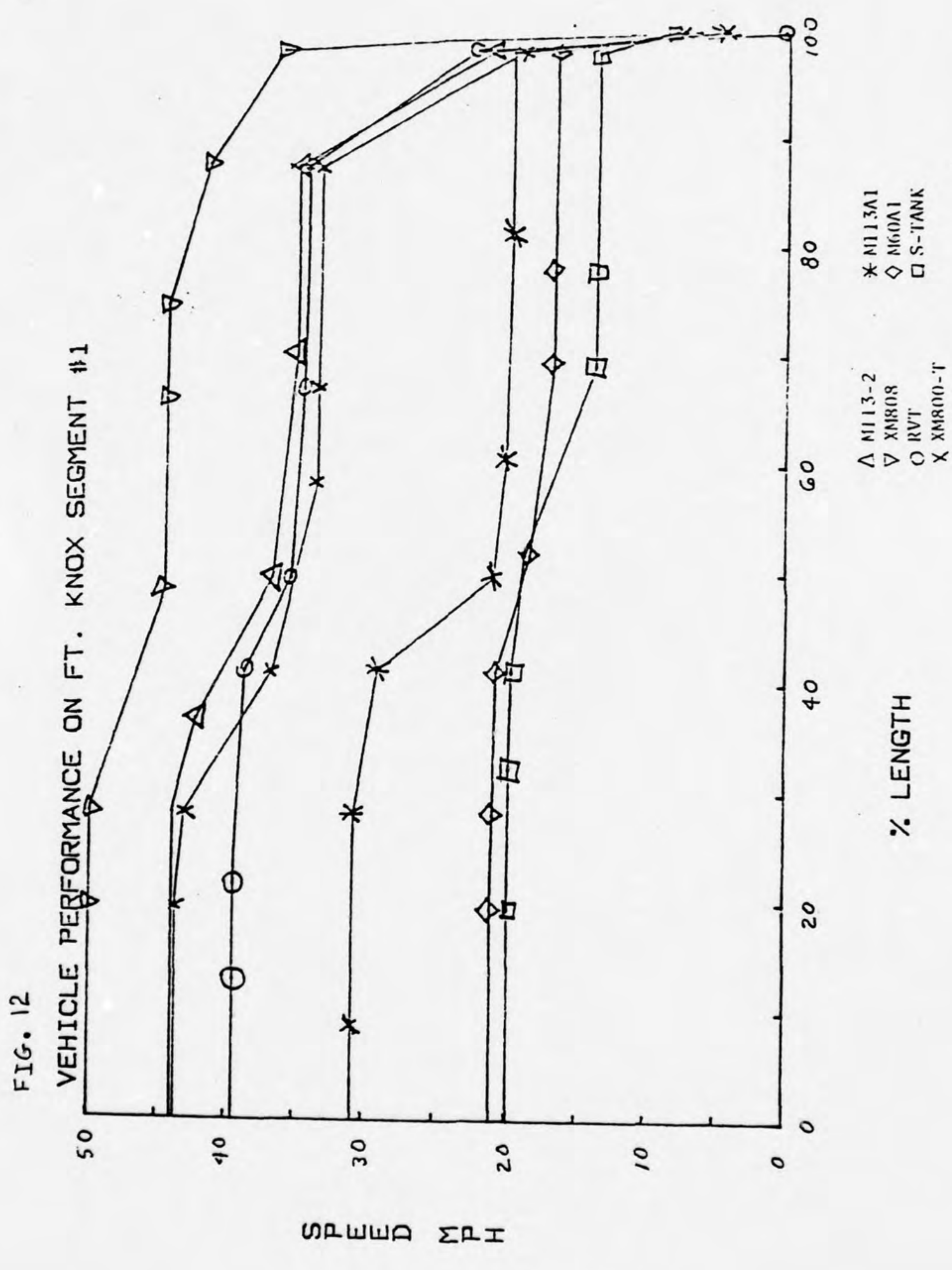


FIG. 12

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #1

FIG. 13

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #2

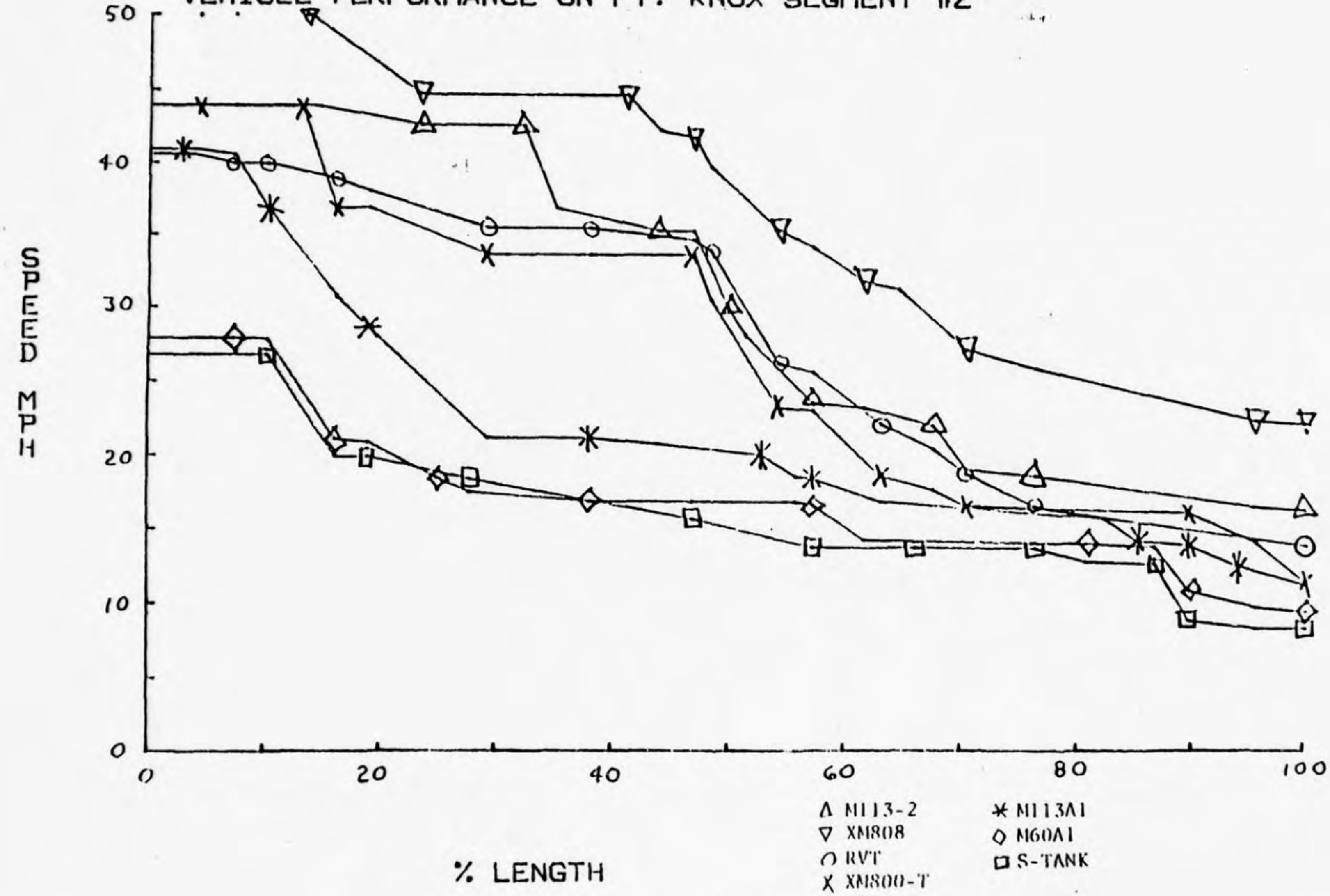


FIG. 14

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #3

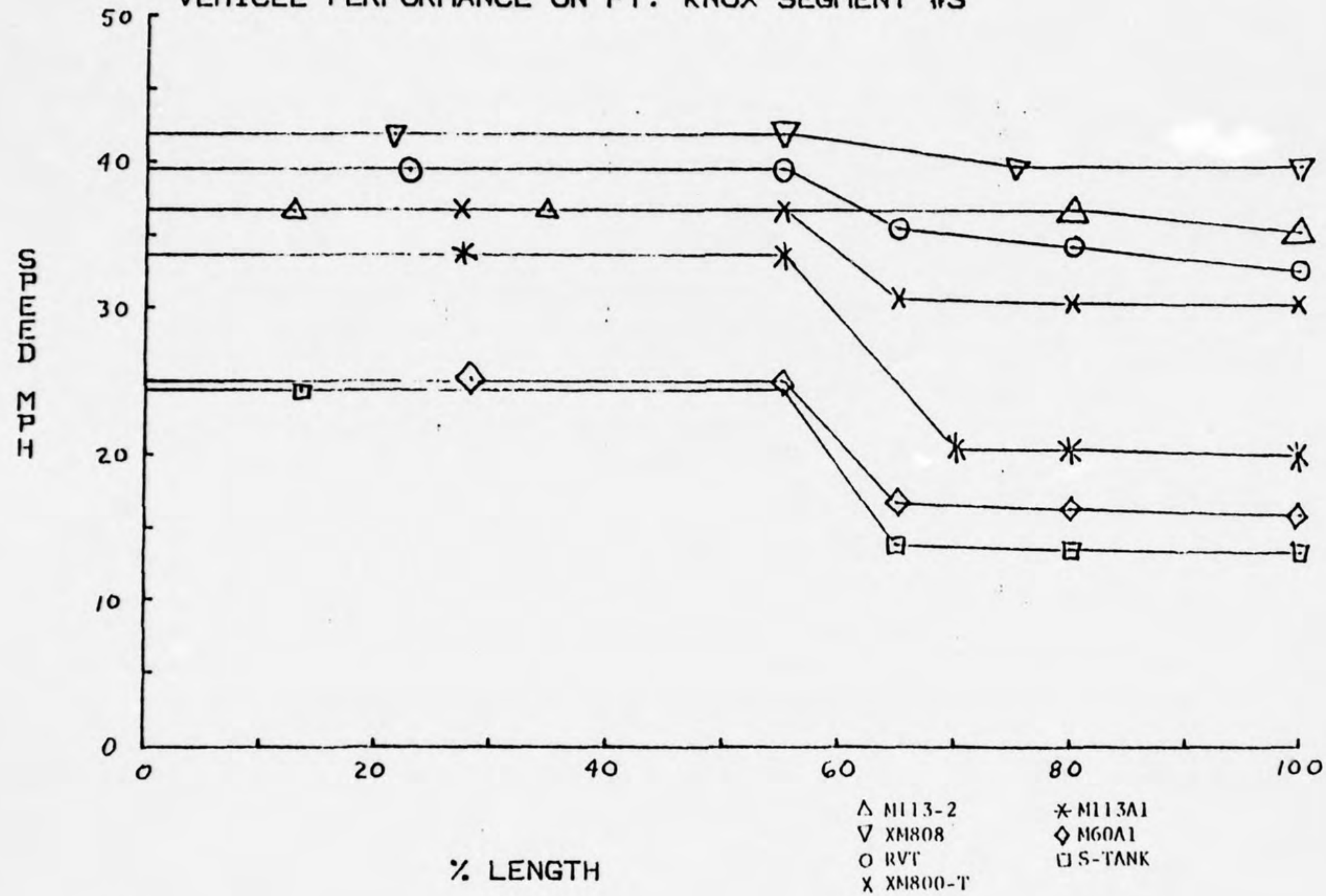


FIG. 15

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #4

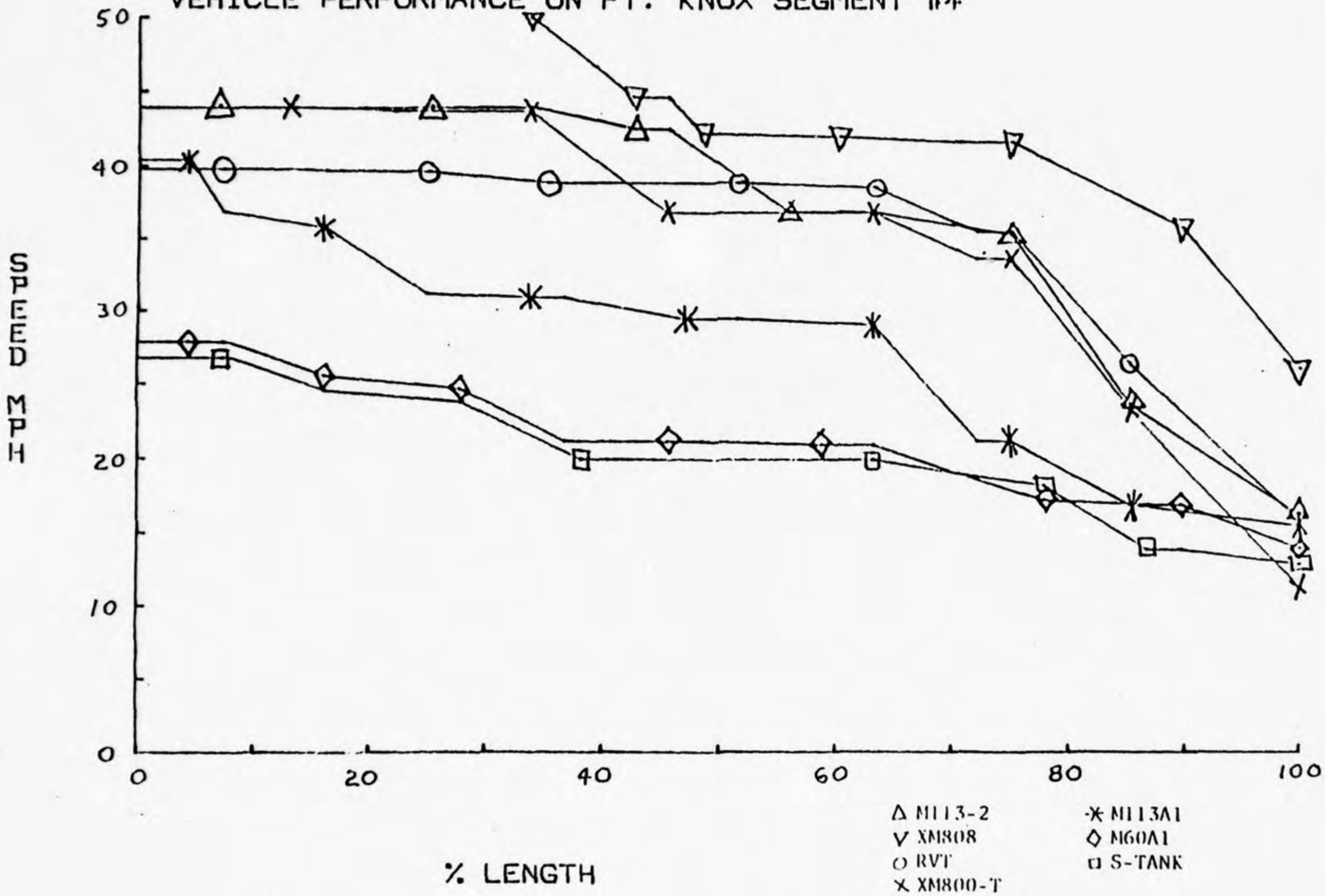


FIG. 16

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #5

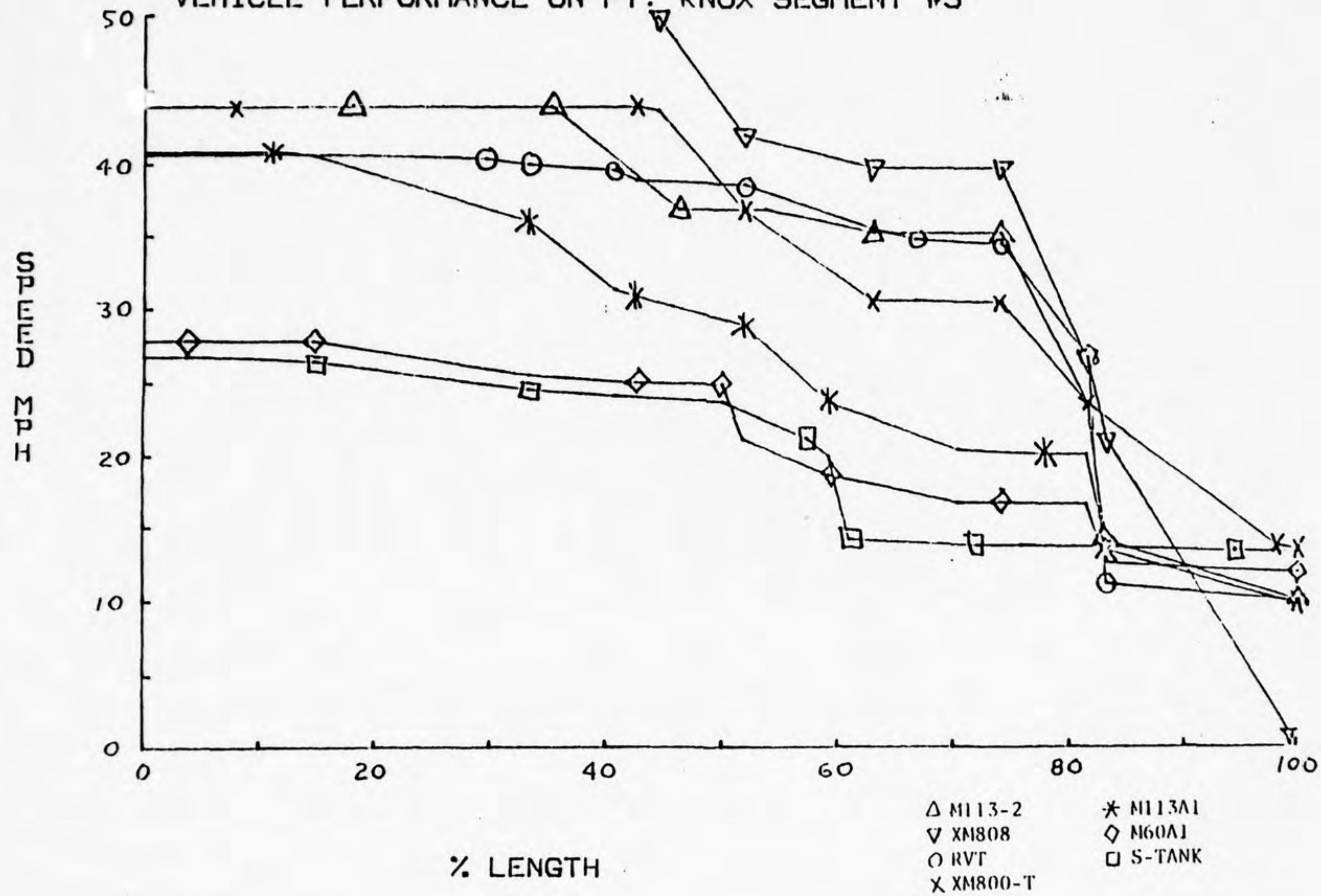


FIG. 17

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #6

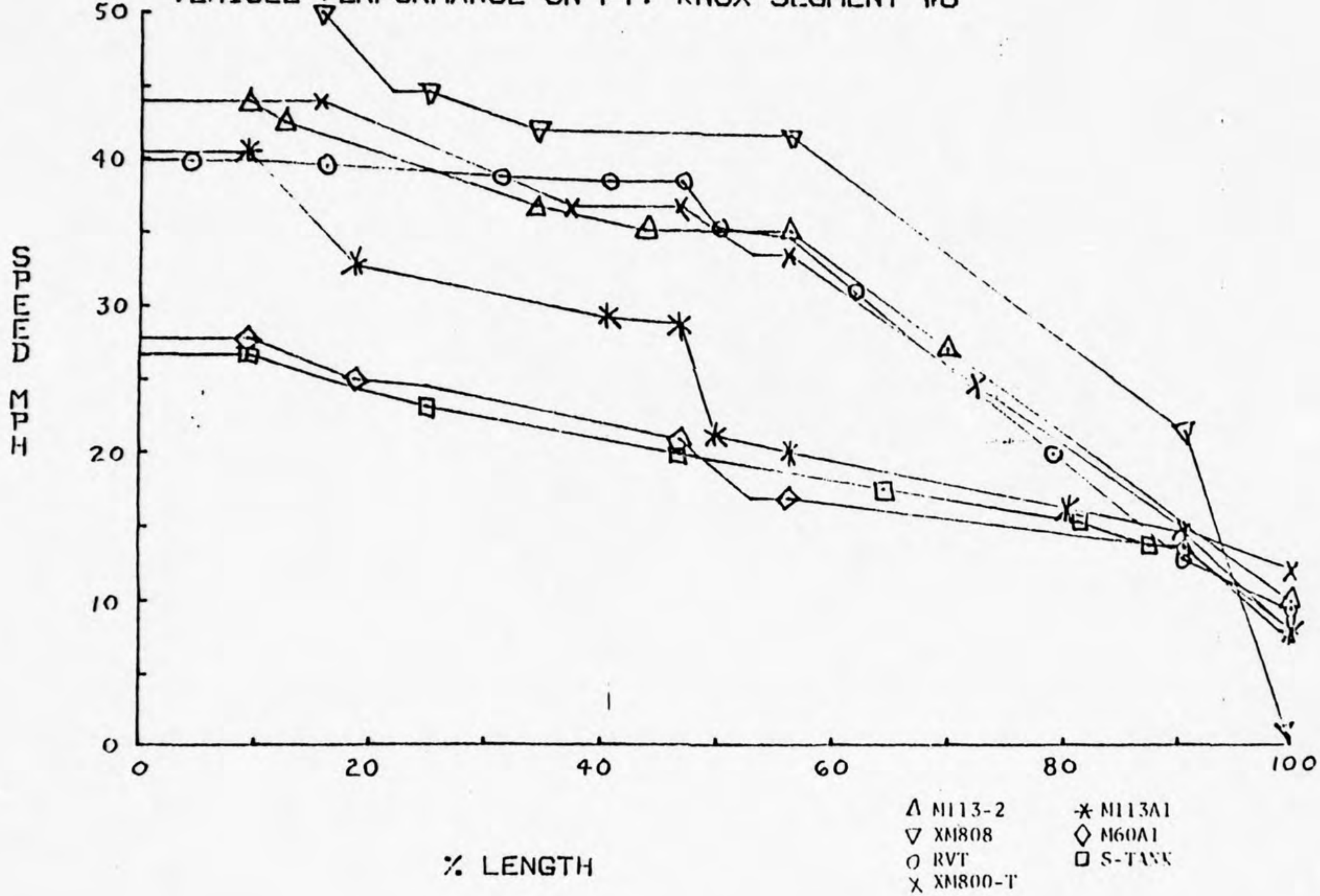


FIG. 18

VEHICLE PERFORMANCE ON FT. KNOX SEGMENT #7

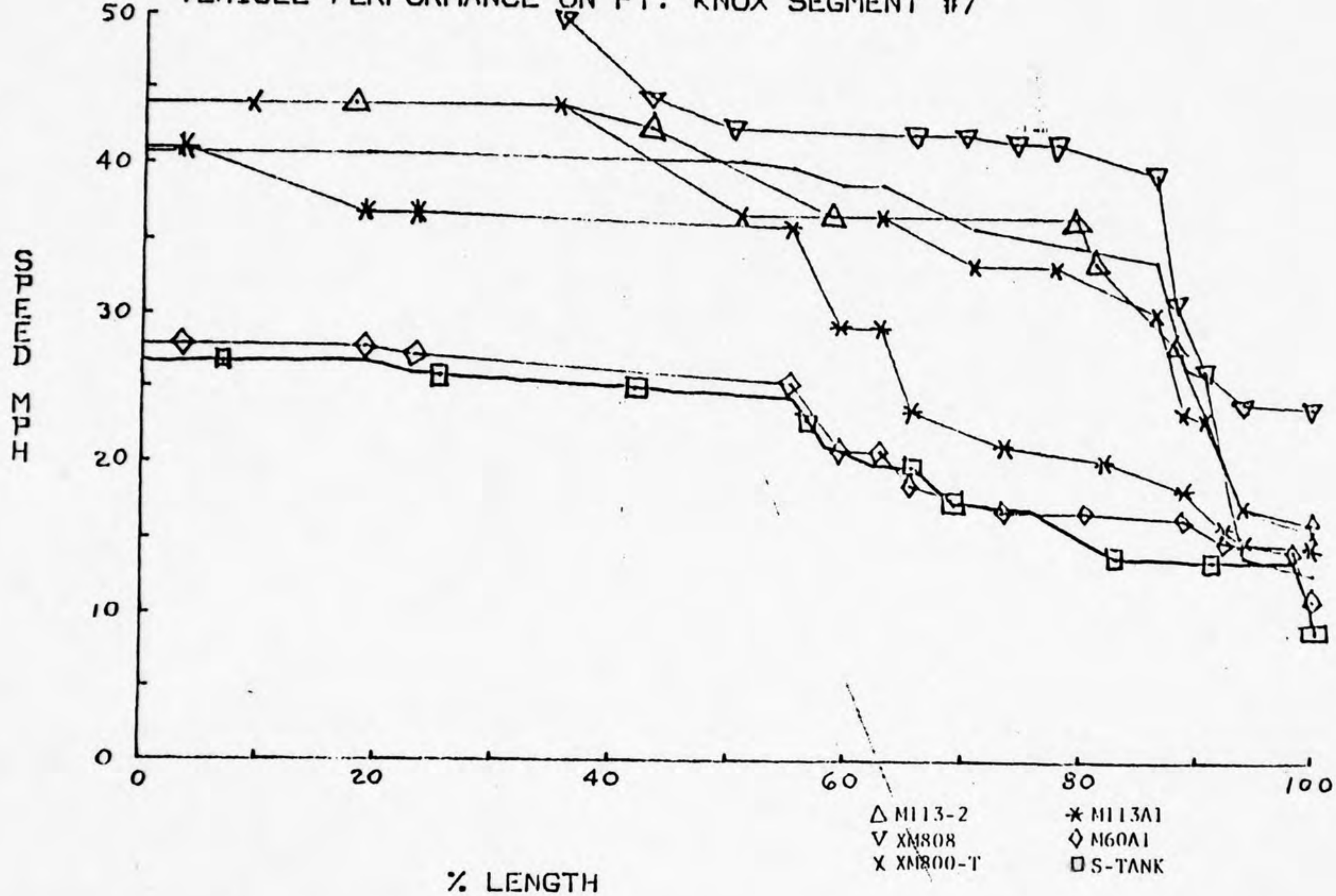


FIG. 19

VEHICLE PERFORMANCE ON FT. KNOX TERRAIN

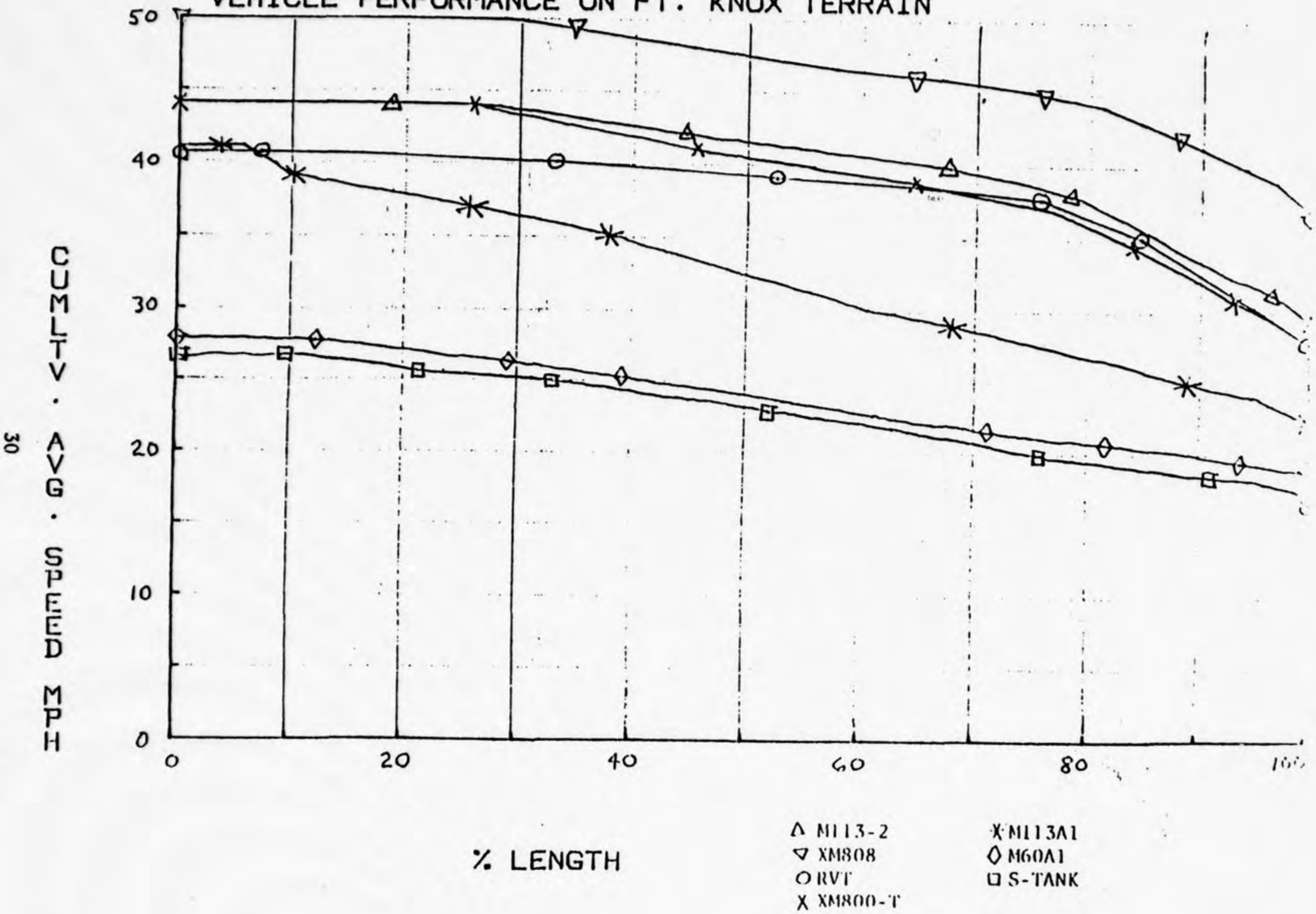
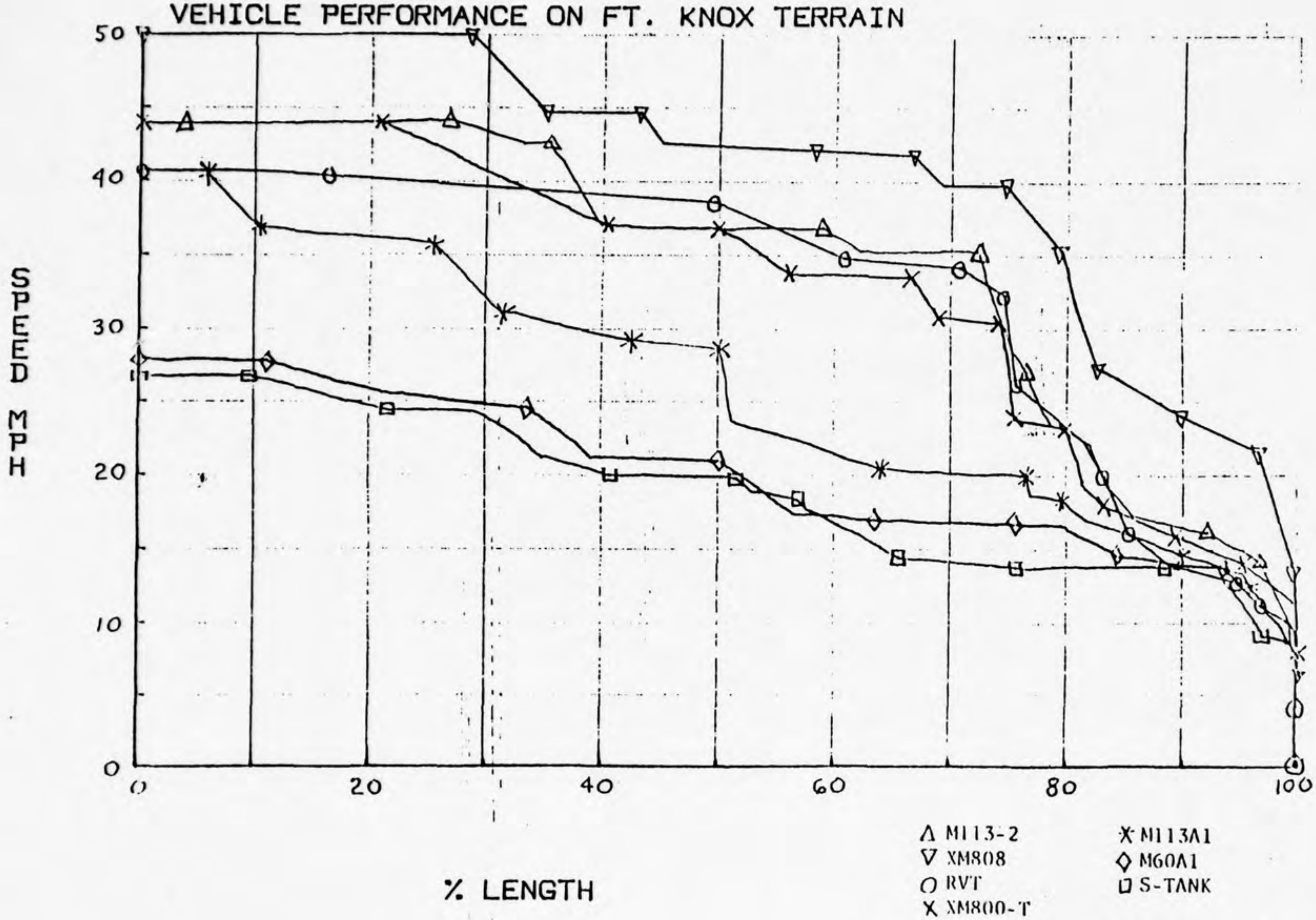


FIG. 20

VEHICLE PERFORMANCE ON FT. KNOX TERRAIN



TABLES

TABLE 1. ACCELERATION PERFORMANCE IN FINE GRAIN SOIL

VEHICLE	RCI	% SLOPE	TIME TO 10 MPH	TIME TO 15 MPH	TIME TO 20 MPH	TIME TO 30 MPH	486 M. CROSSING TIME	366 M. CROSSING TIME	253 M. CROSSING TIME
S-Tank	120	0	5.1	10.9	22.3	-	56.4	45.0	34.0
		20	-	-	-	-	190.8	144.3	100.5
	60	0	6.2	22.9	-	-	73.5	57.3	41.9
		20	-	-	-	-	214.4	162.1	112.9
M60-A1	120	0	3.6	8.2	17.0	-	53.0	42.2	31.6
		20	-	-	-	-	158.0	119.4	83.0
	60	0	4.2	11.9	-	-	64.6	50.5	37.1
		20	-	-	-	-	175.6	132.6	92.1
M113-A1	120	0	2.3	4.9	8.2	29.3	42.5	34.6	26.5
		20	8.9	-	-	-	106.4	80.8	56.7
	60	0	2.5	5.7	10.3	-	53.1	41.4	30.1
		20	-	-	-	-	115.5	87.7	61.4
XM800-T	120	0	1.1	2.2	3.8	8.6	29.7	24.4	19.0
		20	1.9	6.8	-	-	66.7	50.9	36.0
	60	0	1.2	2.4	4.1	10.0	31.7	26.0	20.1
		20	2.1	12.6	-	-	73.5	55.9	39.3
XM-808	120	0	1.3	2.4	3.7	7.6	27.0	22.6	18.0
		20	2.1	5.1	11.4	-	49.4	39.2	29.5
	60	0	1.4	2.6	4.0	8.4	28.6	23.9	18.8
		20	2.3	6.1	-	-	59.6	45.7	32.6
M113-2	120	0	1.0	1.7	2.4	4.6	24.4	19.9	15.5
		20	1.5	2.6	4.2	24.5	40.1	31.2	22.8
	60	0	1.1	1.7	2.5	4.9	25.3	20.8	16.1
		20	1.6	2.8	4.8	-	42.7	33.1	24.0
RVT	120	0	0.9	1.7	2.7	6.3	31.1	24.4	18.1
		20	1.5	3.4	7.5	-	54.8	41.8	29.6
	60	0	1.0	1.8	2.9	7.3	32.5	25.5	18.8
		20	1.6	4.1	12.4	-	56.7	43.4	30.8

TABLE 2. TERRAIN FACTORS DISTRIBUTION

TERRAIN FACTOR	JORDAN	GERMANY	FT. KNOX, KY
Soil Type			
Fine Grain	79.9%	100%	100%
Coarse Grain	20	-	
Wet Season Soil Strength (RCJ/CI)			
>281	1.2	5.0	100
101-160	20	68.4	
61-100	78.8	9.7	
41-60	-	15.4	
33-40	-	1.5	
Slope %			
0-2	78	6.2	12.4
2.1-5	14.6	8.4	28.0
5.1-10	5.7	45.9	28.0
10.1-20	1.5	33.7	3.6
>20	-	5.6	-
Surface Roughness, RMS Inches			
0-6	1.6	5.1	25.3
>.6-.8	4.8	13.4	49.7
>.8-1.2	24.5	21.6	20.8
>1.2-1.6	18.1	17.0	4.2
>1.6-2.2	20.1	18.8	
>2.2-3.2	10.3	14.7	
>3.2	20.5	9.3	
Obstacle Vertical Height, Inches			
0-6	20.3	35.7	65.0
6.1-10	5.7	37.2	17.4
10.1-14	11.4	19.0	14.4
14.1-18	12.4	1.4	3.0
18.1-23.6	26.7	1.3	-
23.7-33.5	5.9	2.6	0.2
>33.5	17.5	2.5	0
Size of Area (or Length of Course)	212 Miles^2	159 Miles^2	23.5 Miles (Length)

TABLE 3. PREDICTED PERFORMANCE ON GERMAN TERRAIN

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	26.9	18.8	1.81
M113-A1	20.1	15.5	4.66
M113-2	25.1	18.4	4.66
XM-808	34.5	24.5	4.63
M60-A1	16.4	11.9	2.56
RVT	28.9	18.6	5.24
S-TANK	15.9	11.7	4.61

TABLE 4. PREDICTED PERFORMANCE ON MID EAST TERRAIN

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	18.2	6.0	13.68
M113-A1	15.5	1.4	17.16
M113-2	15.6	2.9	14.73
XM-808	19.9	0.7	21.77
M60-A1	14.3	5.1	14.66
RVT	16.5	0.4	34.46
S-TANK	13.9	0.5	29.35

TABLE 5. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 1

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	39.8	35.8	0
M113-A1	28.0	23.9	0
M113-2	46.8	37.7	0
XM808	47.6	45.4	0
M60-A1	20.5	18.8	0
RVT	35.4	31.2	0
S-TANK	19.7	16.7	0

TABLE 6. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 2

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	35.7	24.6	0
M113-A1	24.7	19.9	0
M113-2	39.6	27.6	0
XM808	45.2	35.0	0
M60-A1	19.4	16.7	0
RVT	36.3	25.5	0
S-TANK	18.4	15.5	0

TABLE 7. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 3

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	36.8	34.1	0
M113-A1	33.7	27.0	0
M113-2	36.8	36.7	0
XM808	42.0	41.1	0
M60-A1	25.0	20.8	0
RVT	39.6	37.3	0
S-TANK	24.4	18.8	0

TABLE 8. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 4

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	41.3	33.2	0
M113-A1	32.2	26.0	0
M113-2	43.0	35.3	0
XM808	48.1	43.7	0
M60-A1	23.4	20.7	0
RVT	39.2	34.5	0
S-TANK	22.3	19.6	0

TABLE 9. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 5

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	43.1	32.2	0
M113-A1	35.0	24.9	0
M113-2	41.7	31.6	0
XM808	49.5	37.9	0
M60-A1	25.9	20.4	0
RVT	39.9	30.9	0
S-TANK	24.8	19.2	0

TABLE 10. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 6

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	38.6	24.2	0
M113-A1	30.7	21.3	0
M113-2	37.7	24.4	0
XM808	45.0	31.9	0
M60-A1	22.0	18.1	0
RVT	38.7	22.1	0
S-TANK	22.0	18.1	0

TABLE 11. PREDICTED PERFORMANCE ON FT. KNOX SEGMENT NO. 7

VEHICLE	V-50 (MPH)	V-90 (MPH)	% NO-GO
XM800-T	41.7	37.0	0
M113-A1	36.7	28.9	0
M113-2	42.8	38.3	0
XM808	48.3	44.1	0
M60-A1	26.6	22.1	0
RVT	40.5	37.5	0
S-TANK	25.5	20.8	0

TABLE 12. DISTRIBUTION OF LIMITING FACTORS IN TERMS OF PERCENT OF TOTAL AREA FOR WEST GERMAN TERRAIN

VEHICLE	TERRAIN FACTOR LIMITING VEHICLE SPEED									
	RCI LESS THAN VCI_1	TRACTION	OBSTACLES	COMBINED TERRAIN FACTORS	RIDE DYNAMICS	SURFACE AND SLOPE RESISTANCE	VISIBILITY	MANEUVER	TOTAL RESISTANCE	ACCEL. & DECEL.
XM800-T	0	0	1.47	.34	17.93	.24	23.7	13.58	8.87	33.87
M113-A1	0	0	4.31	.35	21.66	9.94	8.53	17.33	16.64	21.25
M113-2	0	0	4.31	.35	33.17	.78	20.11	15.83	.59	24.86
XM808	0	0	4.30	.33	21.15	2.89	36.90	16.95	2.39	15.09
M60-A1	0	0	2.48	.08	7.02	6.54	15.32	20.03	32.18	16.35
RVT	0	0	4.81	.43	22.7	4.27	16.50	18.58	8.13	24.58
S-TANK	0	.63	3.45	.53	13.02	7.51	8.53	19.67	36.29	10.37

TABLE 13. DISTRIBUTION OF LIMITING FACTORS IN TERMS OF PERCENT OF TOTAL AREA FOR MID EAST TERRAIN

VEHICLE	TERRAIN FACTOR LIMITING VEHICLE SPEED									
	RCI LESS THAN VCI_1	TRACTION	OBSTACLES	COMBINED TERRAIN FACTORS	RIDE DYNAMICS	SURFACE AND SLOPE RESISTANCE	VISIBILITY	MANEUVER	TOTAL RESISTANCE	ACCEL. & DECEL.
XM800-T	0	0	13.68	0	27,23	.03	19,50	7.58	.05	31,94
M113-A1	0	0	17.16	0	33,79	2.27	10.27	9,25	.21	27,05
M113-2	0	0	14.73	0	35.43	.08	11,61	9.25	0	28.9
XM808	0	0	21.77	0	28,36	.60	20,94	9.35	0	18,97
M60-A1	0	0	14.66	0	14,72	9.82	15.78	10.68	5.08	29.27
RVT	0	0	34.46	0	31.81	.88	10.78	10,72	0	11,34
S-TANK	0	0	29.35	0	24,39	9.22	7,48	10.97	8.77	9,81

TABLE 14. DISTRIBUTION OF LIMITING FACTORS IN TERMS OF PERCENT OF TOTAL AREA FOR FT. KNOX TERRAIN

	TERRAIN FACTOR LIMITING VEHICLE SPEED									
VEHICLE	RCI LESS THAN VCI_1	TRACTION	OBSTACLES	COMBINED TERRAIN FACTORS	RIDE DYNAMICS	SURFACE AND SLOPE RESISTANCE	VISIBILITY	MANEUVER	TOTAL RESISTANCE	ACCEL. & DECEL.
XM800-T	0	0	0	0	0	5.87	68.57	0	6.45	19.11
M113-A1	0	0	0	0	22.75	13.73	22.00	0	22.99	18.53
M113-2	0	0	0	0	15.96	0	61.46	0	3.47	19.11
XM808	0	0	0	0	1.32	5.54	71.13	0	3.56	18.44
M60-A1	0	0	0	0	13.48	0	13.90	0	56.08	16.54
RVT	0	0	0	0	37.63	10.42	11.83	0	21.34	18.53
S-TANK	0	0	0	0	21.09	5.87	3.47	0	56.16	13.40

TABLE 15. COMPARISON OF MODELING WITH TEST RESULTS

MOBILITY RANKING	DATA SOURCE	EVENT 1	2	3	4	5	6	7	TOTAL COURSE
1	STAGS	XM808 * (17.6)	XM808 (17.4)	XM808 (14.5)	RVT (28.3)	XM808 (19.6)	XM808 (27.25)	XM808 (22.3)	XM808 (21.5)
	MODELING	XM808 (39.3)	XM808 (32.9)	XM808 (40.9)	XM808 (40.9)	XM808 (31.8)	XM808 (28.1)	XM808 (40.7)	XM808 (36.4)
2	STAGS	RVT (15.3)	XM800-T (15.6)	XM800-T (13.2)	XM800-T (22.8)	RVT (16.8)	RVT (27.2)	RVT (21.5)	RVT (21.5)
	MODELING	RVT (34.3)	RVT (23.3)	RVT (36.7)	RVT (30.6)	XM800-T (27.8)	XM800-T (21.9)	XM800-T (32.9)	XM800-T (27.8)
3	STAGS	XM800-T (15.3)	RVT (13.4)	M113A1 (11.1)	XM808 (22.7)	XM800-T (16.7)	XM800-T (23.4)	XM800-T (19.6)	XM800-T (19.5)
	MODELING	XM800-T (31.0)	XM800-T (22.5)	XM800-T (33.6)	XM800-T (27.2)	RVT (24.8)	RVT (19.4)	RVT (32.1)	RVT (27.7)
4	STAGS	M113A1 (12.9)	M113A1 (13.4)	RVT (10.8)	M113A1 (18.6)	M113A1 (15.7)	M113A1 (19.3)	M113A1 (18.2)	M113A1 (16.8)
	MODELING	M113A1 (21.5)	M113A1 (18.7)	M113A1 (25.9)	M113A1 (24.2)	M60A1 (18.9)	M113A1 (18.3)	M113A1 (26.4)	M113A1 (22.4)
5	STAGS	M60A1 (9.7)	S-TANK (10.1)	S-TANK (6.9)	S-TANK (9.3)	S-TANK (11.8)	M60A1 (14.3)	M60A1 (13.4)	S-TANK (12.3)
	MODELING	M60A1 (18.0)	M60A1 (15.6)	M60A1 (20.1)	M60A1 (19.8)	M113A1 (21.1)	M60A1 (16.0)	M60A1 (20.8)	M60A1 (18.5)
6	STAGS	S-TANK (8.3)	M60A1 (7.8)	M60A1 (6.8)	M60A1 (14.3)	M60A1 (11.2)	S-TANK (13.5)	S-TANK (12.4)	M60A1 (12.2)
	MODELING	S-TANK (16.0)	S-TANK (14.3)	S-TANK (17.9)	S-TANK (18.6)	S-TANK (18.3)	S-TANK (15.8)	S-TANK (19.5)	S-TANK (17.3

* Numbers in parenthesis are speeds in MPH.

TABLE 16. MOBILITY PERFORMANCE SUMMARY

TERRAIN		MOBILITY RANKING 1	2	3	4	5	6	7
	VEHICLE	XM808	XM800T	RVT	M113-2	M113A1	M60A1	S-TANK
GERMANY	V_{50}	34.5	26.9	28.9	25.1	20.1	16.4	15.9
	V_{90}	24.5	18.8	18.6	18.4	15.5	11.9	11.7
	% NO GO	4.6	1.8	5.2	4.7	4.7	2.6	4.6
	VEHICLE	XM800T	M60A1	M113-2	M113A1	XM808	S-TANK	RVT
JORDAN	V_{50}	18.2	14.3	15.6	15.5	19.9	13.9	16.5
	V_{90}	6.0	5.1	2.9	1.4	0.7	0.5	0.4
	% NO GO	13.7	14.6	14.7	17.2	21.8	29.4	34.5
	VEHICLE	XM808	M113-2	XM800T	RVT	M113A1	M60A1	S-TANK
FDTE (FORT KNOX)	V_{50}	47.3	41.4	40.5	39.6	33.5	24.2	23.1
	V_{90}	41.2	33.7	32.0	32.5	25.0	19.9	13.5
	% NO GO	-	-	-	-	-	-	-

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2. USAE Waterways Experiment Station, Vicksburg, Mississippi, Results of WES Tests in Support of the STAGS Program at Ft. Knox, Kentucky, 17 February 1976.

3. US Army Engineer Waterways Experiment Station and US Army Tank-Automotive Command, The AMC '71 Ground Mobility Model, Technical Report 11789 (22143).

4. AMSAA Technical Memorandum No. 158; A Terrain Analysis of Four Tactical Situations, W. K. Olson; December 1972.

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APPENDIX A

VEHICLE CHARACTERISTICS

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VEHICLE CHARACTERISTICS

IDENTIFICATION	XM800T	M113-A1	M113-2	XM-808	M60-A1	RVT	S-TANK
Vehicle Type	Tracked	Tracked	Tracked	Wheeled	Tracked	Tracked	Tracked
Gross Veh. Weight (Lbs)	15,500	20,000	19,060	17,200	100,000	57,400	86,000
Veh. Length (Ins.)	202	192	192	225	273	251	272
Veh. Width (Ins.)	98	105	105	105	143	122	133
Height of Veh. Pushbar (Ins.)	30	30	30	16	45	42	46
Front End Clearance (Ins.)	30	30	30	16	45	42	46
Ground Clearance at Center of Greatest Span (Ins.)	-	-	-	13.4	-	-	-
Rear End Clearance (Ins.)	34.5	23	23	15.8	40	24	56
Dist. CG. to Center of Rear Wheel (Ins.)	78	91	91	100	120.7	99	93
Transmission Type	Auto.	Auto.	Auto.	Auto.	Auto.	Auto.	Auto.
Max. Span Between Adjacent Wheel Centerlines (Ins.)	-	-	-	50	-	-	-
Veh. Approach Angle (Deg.)	90	70	70	90	90	31	31
Angle Between Line Parallel to Ground & Line From CG to Rear Wheel (Deg.)	5.7	17.2	17.2	-	4.6	6.5	4
Max. Force Pushbar can Withstand (Lbs)	31,000	40,000	40,000	35,000	200,000	114,800	172,000

VEHICLE CHARACTERISTICS (Continued)

IDENTIFICATION	XM800T	M113-A1	M113-2	XM-808	M60-A1	RVT	S-TANK
Track or Wheel Width (Ins.)	17	15	15	18	28	21	26.4
Wheel Rim Diameter (Ins.)	-	-	-	20	-	-	-
Roadwheel Radius Plus Track Thickness (Ins.)	14.5	14.5	14.5	-	17	16.75	18.4
Sprocket Pitch Radius or Tire Rolling Radius (Ins.)	10.8	9.8	9.8	19.5	12.25	16.6	10.75
Tire Pressure (PSI)	-	-	-	8	-	-	-
Tire Ply Rating	-	-	-	4	-	-	-
Min. Ground Clearance (Ins.)	16	16	16	13.4	18	15.75	15.25
Rear Idler or Sprocket Radius Plus Track Thickness (Ins.)	10.8	11.3	11.3	-	15.25	16.75	13
Area of One Track Shoe (Ins.) or No. Axles	103	90	90	4	194	126	131.8
Length of Track on Ground or Wheel Diameter (Ins.)	118	105	105	45	167	134	112.8
Horizontal Dist. From CG to Front Wheel Centerline (Ins.)	69.3	52	52	86	77.2	60	52.2
# of Bogies, if Wheeled Vehicle Does Have Chains	8	10	10	NO	12	10	8
Grouser Height (Ins.) or # of Tires	1	1	1	8	1.5	1.5	1

VEHICLE CHARACTERISTICS (Continued)

IDENTIFICATION	XM800T	M113-A1	M113-2	XM-808	M60-A1	RVT	S-TANK
Track Type	Flex.	Flex.	Flex.	-	Flex.	Flex.	Flex.
Departure Angle	79.0	40.0	40.0	90	42.5	26	37
Vert. Dist. Ground to Center Rear Spricket or Idler (Ins.)	26	15	15	-	43	34.0	32.25
Vert. Dist. CG to Roadwheel Centerline (Ins.)	26	24	24	13	36	27.25	26
Max. Braking Force Vehicle can Develop (Lbs)	868,000	10,200	10,673	13,700	30,000	45,920	43,000
Horsepower/Ton	36	21.5	78.7	67.7	15	62.7	17
Dist. Between 1st & Last Wheel Centerlines	118	105	105	172.6	167	127.8	112.8

VEHICLE CHARACTERISTICS (Continued)

VEHICLE IDENTIFICATION

XM800-T		M113-A1		M113-2		XM-808		M60-A1		RVT		S-TANK	
TRACTIVE FORCE	SPEED	TRACTIVE FORCE	SPEED	TRACTIVE FORCE	SPEED	TRACTIVE FORCE	SPEED	TRACTIVE FORCE	SPEED	TRACTIVE FORCE	SPEED	TRACTIVE FORCE	SPEED
16450	0	15850	0	19000	0	22600	0	72790	0	45000	0	40000	0
16450	1	15800	1.8	17000	2.5	19000	2	62800	1.4	44800	2	35500	2
15280	2	14250	1.9	14500	5	15100	4	52850	2.3	44000	4	33000	3
13900	3	12750	2	13400	7.5	11600	6	42910	3.5	43000	5	30200	4
11400	5	11250	2.5	12000	10	11000	8	38000	4.5	41000	6	27000	5
6610	10	9750	3.2	11000	12.5	10110	10.2	33020	5.5	34000	7	22800	6
5530	12	8770	3.9	10000	15	8320	10.3	28100	6.8	32000	7.2	17500	6.9
4540	15	8030	4.8	9000	17.5	7330	12	23200	8	31800	8	17000	8
3960	18	7380	5.8	8000	20	6840	12.1	14600	12	31200	10	16600	9
3730	20	6990	7	7100	22.5	6450	13.5	10800	16	30000	11.5	15700	10
3580	21	6975	7.5	6400	25	6175	20	9100	20	29000	12	14250	11
3470	22	6650	8	5800	27.5	4900	20.1	7100	24	26200	13	12400	12
2630	25	6050	9.5	5250	30	4820	25	6700	26	20600	13.8	9700	13.2
2610	27	5300	10.8	4750	32.5	4640	28	6000	28	20500	15	8750	16
2600	28	4100	10.9	4400	35	3760	28.1	3000	30	20000	17.5	7400	20
2540	30	3700	12	3900	40	3680	30	2000	31	19000	19	3500	30
2500	32	3500	13.1	3200	50	3650	39	0	31.1	18000	20	0	30.1
2310	34	3450	15	2750	60	3200	39.1			16300	21		
2230	36	3300	17.1	0	60.1	3150	45			12500	22		
2050	38	3000	19.2			3100	50			12400	25		
2050	40	2500	21.3			3000	55			12000	28		
2030	42	1850	21.4			2900	65			11000	32.5		
1988	44	1815	25.3			0	65.1			9500	35		
1910	46	1785	29							7000	37		
1830	48	171	33							4000	40		
1750	50	1550	37.1							2000	42		
1655	51.3	1300	41.1							0	42.1		
0	51.4	0	41.2										

VEHICLE CHARACTERISTICS (Continued)

VEHICLE IDENTIFICATION

XM800-T		M113-A1		M113-2		XM-808		M60-A1		RVT		S-TANK	
OBSTACLE HEIGHT	SPEED	OBSTACLE HEIGHT	SPEED	OBSTACLE HEIGHT	SPEED	OBSTACLE HEIGHT	SPEED	OBSTACLE HEIGHT	SPEED	OBSTACLE HEIGHT	SPEED	OBSTACLE HEIGHT	SPEED
0	51	0	42	0	60	0	65	0	30	0	42	0	30
3.8	51	6	42	6	60	6.3	65	7	30	6	42	7	30
4.1	40	6.4	30	6.07	50	6.5	60	8	20	6.6	26.5	8	24
4.5	30	7	20.8	6.1	40	6.9	50	9	14	7.4	18.5	9	20
5.4	20	7.5	17.3	6.2	35	7.5	40	10	12	8	15	10	17.5
7	12	8	15	6.4	30	8	34	12.5	10	9	11.5	11	15.5
8	10.5	10	10.8	6.6	26	9.5	30	14	8.5	10	9	12	13.8
12	7.8	12.6	7	6.8	23	10.6	24	20	6	11	7.5	14	10.9
20	6	13.8	6	7	20.8	12	20	30	5.5	12	6.2	17	8.2
40	2	15	5	7.5	17	14	15	40	5	14	5	20	7
100	2	17	2.4	8	15	18	9.2	100	5	17	4.2	40	5
		40	2	10	10.8	40	5.1			20	3.5	100	5
		100	2	12.6	7	100	2			40	2		
				13.8	6		2			100	2		
				15	5								
				17	2.4								
				40	2								
				100	2								

VEHICLE CHARACTERISTICS (Continued)

VEHICLE IDENTIFICATION

XM800-T		M113-A1		M113-2		XM-808		M60-A1		RVT		S-TANK	
RMS	SPEED	RMS	SPEED	RMS	SPEED	RMS	SPEED	RMS	SPEED	RMS	SPEED	RMS	SPEED
0	51	0	42	0	60	0	65	0	30	0	42	0	30
.55	51	.4	40	.22	60	.28	65	1.6	30	.25	42	.85	30
.75	41.8	.5	35.2	.28	50	.33	60	1.7	25	1	35.3	1.5	19
1.	32.5	.62	30	.4	40	.4	56	1.9	20	2	14.8	2	13.7
1.32	25.8	.84	25	.5	35.2	.5	51	2.2	16	3	7.9	2.5	10.4
1.5	23	1.18	20	.62	30	.7	45	2.5	14	4	7.2	3	8.5
1.72	20.5	1.4	18	.84	25	.9	40	3	12	5	6.8	3.5	7.8
2.5	15.3	1.66	16	1.18	20	1.2	34	3.5	10	6	6.1	4	7.5
4	11	2.1	14	1.4	18	1.45	30	4	8.5	7	5.8	5	7
4.5	10.5	2.8	12	1.66	16	2.12	20	5	7.5	8	5	8	5
8	10.5	4	9.5	2.1	14	2.8	10	6	6.5				
		4.95	8	2.8	12	3.	7	8	5.2				
		6	6	4.9	5	4.	3						
		8	2	4.95	8	8.	2						
				6	6								
				8	2								

APPENDIX B

COMPARISON OF MODELING PREDICTIONS WITH TEST PERFORMANCE DURING ARSV MOBILITY TESTS AT FORT KNOX

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APPENDIX B

COMPARISON OF MODELING PREDICTIONS WITH TEST PERFORMANCE DURING ARSV MOBILITY TESTS AT FORT KNOX

TYPE OF TESTS	AVERAGE SPEED, MPH				
		XM800W "A"	XM800T "A"	M113A1	M551
Terrain Units (14 Total)	Test	17.5	16.5	14.1	12.4
	AMC 71	18.7	16.9	14.4	13.0
Traverse Tests (4 Total)	Test	16.5	15.3	13.6	11.2
	AMC 71	17.2	15.7	12.8	12.0

Note: Drivers used for testing were experienced civilian test drivers.

Test Data Source: Mobility validation test results for the Armored Reconnaissance Scout and Comparison Vehicles; Waterways Experiment Station Misc. Paper M-74-6; August 1974.

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